THE ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES, 122:331–353, 1999 May

THE $A\,^3\Phi$–$X\,^3\Delta$ SYSTEM (γ BANDS) OF TiO: LABORATORY AND SUNSPOT MEASUREMENTS

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Received 1998 June 2; accepted 1998 December 3

ABSTRACT

The spectrum of the $A\,^3\Phi$–$X\,^3\Delta$ system of TiO has been measured in the laboratory as well as in sunspots. In the laboratory, the bands were excited in a hollow cathode lamp and were observed using a Fourier transform spectrometer. These bands were also identified in the spectrum of a sunspot umbra recorded with the same spectrometer. Both laboratory and solar measurements have been combined with jet-cooled laser measurements and pure rotational frequencies in the $X\,^3\Delta$ ground state to obtain improved molecular constants for the $A\,^3\Phi$ and $X\,^3\Delta$ states of TiO. RKR potential energy curves and Franck-Condon factors were also calculated.

Subject headings: line identification — methods: laboratory — molecular data — sunspots

1. INTRODUCTION

TiO is a widely investigated molecule because of its importance in astrophysics and in quantum chemistry. In total, six singlet states ($a\,^1\Delta$, $d\,^1\Sigma^+$, $b\,^1\Pi$, $c\,^1\Phi$, $f\,^1\Delta$, and $e\,^1\Sigma^+$) and five triplet states ($X\,^3\Delta$, $E\,^3\Pi$, $A\,^3\Phi$, $B\,^3\Pi$, and $C\,^3\Delta$) have been known for some time (Huber & Herzberg 1979 and references therein). Recently four additional highly excited triplet states, $G\,^3\Phi$, $H\,^3\Phi$, $I\,^3\Pi$, and $J\,^3\Pi$, have been observed using the technique of optical-optical double resonance spectroscopy (Barnes, Merer, & Metha 1997). The $X\,^3\Delta$ ground state of TiO has been well characterized by Hocking, Gerry, & Merer (1979), who analyzed several vibrational bands of the $B\,^3\Pi$–$X\,^3\Delta$ transition. Since that time the $B\,^3\Pi$–$X\,^3\Delta$ system has reinvestigated by Gustavsson et al. (1991), Fletcher et al. (1993), and Amiot et al. (1995). Fletcher et al. (1993) measured the hyperfine splitting for a few low J lines of the 0–0 band of the $B\,^3\Pi$–$X\,^3\Delta$ system and determined hyperfine parameters for the ground state of TiO, while Amiot et al. (1995) remeasured the 1–0 band of the $B\,^3\Pi$–$X\,^3\Delta$ transition with a sub-Doppler resolution of 0.002 cm^{-1}. Amiot et al. (1995) measured 42 main and satellite branches with J up to 95 and provided an improved set of molecular constants for the vibrational ground state of TiO. The $C\,^3\Delta$–$X\,^3\Delta$ system has been investigated by Gustavsson et al. (1991), and the $E\,^3\Pi$–$X\,^3\Delta$ system has been studied by Simard & Hackett (1991). A pure rotational transition in the $X\,^3\Delta_1$ state was measured by Steimle et al. (1990), and more recently several pure rotational transitions in the $X\,^3\Delta_1$, $X\,^3\Delta_2$, and $X\,^3\Delta_3$ spin component have been measured by Namiki et al. (1998). Other recent experimental work on TiO includes the remeasurement of the 0–0 band of the $c\,^1\Phi$–$a\,^1\Delta$ system (β bands) by laser spectroscopy in an effusive molecular beam (Amiot et al. 1996). The TiO bond dissociation energy (D_0) has been confirmed to be 6.87 eV (Naulin et al. 1997). Kaledin, McCord, & Heaven (1995) have redetermined the $X\,^3\Delta$–$a\,^1\Delta$ energy separation in TiO, which has also been discussed by Amiot et al. (1996). Finally, a photoelectron spectrum of TiO and other titanium oxides has been recorded by Wu & Wang (1997).

The visible and near-infrared spectrum of TiO is noticeably present in the spectra of M-type stars (Fowler 1904; Kirkpatrick, Henry, & McCarthy 1991; Valenti, Piskunov, & Johns-Krull, 1998). TiO has also been identified in sunspots by several workers over the span of almost a century. The green α-bands ($C\,^3\Delta$–$X\,^3\Delta$) of TiO were identified by Hale, Adams, & Gale (1906), the red γ bands ($A\,^3\Phi$–$X\,^3\Delta$) were identified in sunspot spectrum by Hale & Adams (1907), and more recently the $B\,^3\Pi$–$X\,^3\Delta$ transition (yellow-red γ' bands) was identified by Wöhl (1971). The $c\,^1\Phi$–$a\,^1\Delta$ transition (β bands) has also been identified by Sotirovski (1972) in sunspots. The α and γ systems have also been investigated in sunspots by several other workers (Makita 1968; Weber 1971; Sotirovski 1971, 1972; Lambert & Mallia 1972; Engvold 1973). Lambert & Mallia (1972) have used their spectra of TiO to determine temperatures and the Ti isotope abundances in sunspots. Phillips & Davis (1987) and Clegg, Lambert, & Bell (1979) have used similar data to estimate the temperature of M-type stars. Schwenke (1998) has calculated the molecular opacity of TiO by combining both experimental data and ab initio calculations.

The TiO molecule serves as a model for the role of d electrons in chemical bonding of transition metal elements, and there are several theoretical studies of the spectroscopic properties available in the literature. In early work Carlson & Nesbet (1964) and Carlson & Moser (1967) have performed Hartree-Fock calculations on the low-lying electronic states $X\,^3\Delta$, $a\,^1\Delta$, and $d\,^1\Sigma^+$ in an attempt to predict spectroscopic properties. In another paper Bauschlicher, Langhoff, & Komornicki (1990) have performed CAS SCF calculations on a number of electronic states including $X\,^3\Delta$, $a\,^1\Delta$, $d\,^1\Sigma^+$, $A\,^3\Phi$, $E\,^3\Pi$, and for an unobserved low-lying $^3\Sigma^-$ state. Schamps, Sennesal, & Carette (1992) performed ab initio calculations on TiO to determine the predominant configurations and CI wave functions of the observed electronic states. From these calculations they concluded that the electronic wave functions are reasonably well represented by single configurations. Most recently, Langhoff (1997) has calculated the oscillator strengths of TiO bands which can be compared with some recent measurements by Hedgecock et al. (1995).

Recently we have reported an analysis of the $b\,^1\Pi$–$a\,^1\Delta$ system (δ bands) of TiO using laboratory and sunspot measurements and have provided an improved set of molecular

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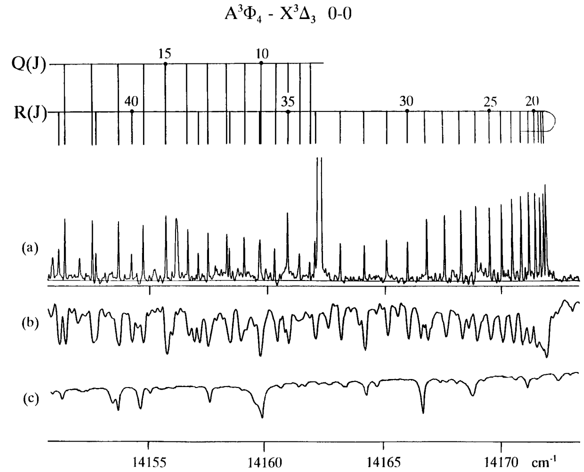

FIG. 1.—Part of the spectrum of the 0–0 band of the $A\,^3\Phi$–$X\,^3\Delta$ system of TiO. (*a*) Laboratory spectrum. (*b*) Sunspot spectrum. (*c*) Photospheric spectrum.

constants for the $b\,^1\Pi$ and $a\,^1\Delta$ states (Ram, Bernath, & Wallace 1996). A detailed account of the previous spectroscopic studies on TiO may be found in the papers by Barnes et al. (1996, 1997), Ram et al. (1996), and the review by Merer (1989).

Although the $A\,^3\Phi$–$X\,^3\Delta$ transition has already been identified in sunspot spectra, high-resolution measurements of many of the line positions are still lacking. The initial high-temperature measurements of the $A\,^3\Phi$–$X\,^3\Delta$ bands were made at grating resolution by Phillips (1973). Recently Barnes et al. (1996) reported high-resolution measurements of some low J lines ($J'' \leq 25$) in the 0–0 band of the $A\,^3\Phi$–$X\,^3\Delta$ transition. The existing spectroscopic constants, however, do not reproduce the TiO observations in sunspots and stellar spectra. We have decided, therefore, to reinvestigate the $A\,^3\Phi$–$X\,^3\Delta$ transition of TiO at high resolution with the aim of providing improved spectroscopic constants. In this work we have measured the lines in several bands of the $A\,^3\Phi$–$X\,^3\Delta$ transition of TiO at high resolution with a Fourier transform spectrometer in the laboratory as well as in sunspot spectra. An improved set of molecular constants have been obtained for the ground and excited states by combining these data with the existing pure rotational measurement of Steimle et al. (1990) and Namiki et al. (1998), the $A\,^3\Phi$–$X\,^3\Delta$ measurements of Barnes et al. (1996) and the laser spectroscopic measurements of the 1–0 band of the $B\,^3\Pi$–$X\,^3\Delta$ transition (Amiot et al. 1995).

2. EXPERIMENTAL

2.1. *Laboratory Observations*

The $A\,^3\Phi$–$X\,^3\Delta$ TiO bands were present in the same spectra in which the $b\,^1\Pi$–$a\,^1\Delta$ transition of TiO was identified (Ram et al. 1996). The details of the experimental methods used in this observation have been provided previously (Ram et al. 1996). Briefly, the TiO bands were observed in a titanium hollow cathode lamp during a search for TiH and TiD spectra in the red and near-infrared regions. In addition to the complex bands of TiH and TiD near 1 μm, we observed TiO as an impurity in the 10000–15000 cm^{-1} region. The TiO bands in the TiD experiments were much stronger than those in the TiH experiments. Although we did not add any O_2 gas to the lamp, strong TiO bands were observed, presumably from the oxygen-containing impurities present either on the surface of the cathode or in the experimental system.

The spectra in the 10000–16000 cm^{-1} region were recorded at 0.02 cm^{-1} resolution using the 1 m Fourier transform spectrometer associated with the McMath-Pierce Solar Telescope of the National Solar Observatory. Si-diode detectors, a quartz beam splitter, and OG570 filters were used,

The spectral line positions were extracted using a data reduction program called PC-DECOMP developed by J. Brault. The peak positions were determined by fitting a Voigt line shape function to each spectral feature. The spectra were calibrated using the measurements of the Ne atomic lines provided by Palmer & Engelman (1983). The TiO lines have average widths of about 0.042 cm^{-1} and appear with a maximum signal-to-noise ratio of about 20:1 in the 0–0 band, so the absolute accuracy and precision of the measurements in strong bands is expected to be of the order of ± 0.002 cm^{-1}. The measurement precision in weaker bands, however, varies from ± 0.002 to ± 0.005 cm^{-1} depending upon signal-to-noise ratio and extent of blending.

2.2. *Solar Observations*

The TiO molecular lines were also identified in the spectrum of a sunspot umbra recorded in 1981 March with the Fourier transform spectrometer of the McMath-Pierce Solar Telescope. In addition to the δ-system ($b\,^1\Pi$–$a\,^1\Delta$) and a few lines of the ϕ-system ($b\,^1\Pi$–$d\,^1\Sigma^+$), the lines of the γ-system ($A\,^3\Phi$–$X\,^3\Delta$) of TiO have also been identified. The spectrum extended from about 9000 to 17000 cm^{-1} and had an unapodized resolution of 0.055 cm^{-1}. The TiO δ-lines ($b\,^1\Pi$–$a\,^1\Delta$) are present in the 10960–11250 cm^{-1} region, while the lines of the γ-system ($A\,^3\Phi$–$X\,^3\Delta$) of TiO are present in the 12000–14500 cm^{-1} region and appear with a depth of about 15%. In spite of overlapping from several Zeeman split atomic lines, many telluric lines and numerous unidentified solar lines, the strong TiO bands (e.g., 0–0 band) can clearly be noticed in the sunspot spectra (Fig. 1). Although the lines in the higher vibrational bands are not obvious at first glance, the line positions from the laboratory spectra and the prediction of high J lines based on the spectroscopic constants were very helpful in identifying the weaker TiO lines. The measurement uncertainty for the solar lines is expected to be of the order of ± 0.005 cm^{-1} or higher.

3. DATA ANALYSIS AND DISCUSSION

The γ bands ($A\,^3\Phi$–$X\,^3\Delta$) of TiO are much stronger in intensity than the δ bands ($b\,^1\Pi$–$a\,^1\Delta$) in our spectra. The laboratory spectra consist of the $\Delta v = 0$ and ± 1 sequence bands of the $A\,^3\Phi$–$X\,^3\Delta$ transition with vibrational levels up to $v = 4$ in the ground and the excited state. Each vibrational band has three subbands and each subband consists of three branches, P, Q, and R, with no Λ-doubling splitting even at the highest J values measured. Although Ti has five isotopes—^{46}Ti (8%), ^{47}Ti (7.3%), ^{48}Ti (73.8%), ^{49}Ti (5.5%), and ^{50}Ti (5.4%)—only ^{48}TiO lines were identified in our spectra. A part of the laboratory spectrum of the 0–0 band is presented in Figure 1, along with the corresponding sunspot spectrum. As can be seen in Figure 1, there is a very good correspondence between the molecular features of the

TABLE 1

Observed Line Positions (in cm^{-1}) for the $A\,^3\Phi$–$X\,^3\Delta$ System of TiO

J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$
							$A\,^3\Phi_2$–$X\,^3\Delta_1$ 0–0								
3....	2	14022.5990	−6	72...	71	13957.2660 a	93	63....	64	13847.8217	24	43....	43	13971.3820 a	10
4....	3	14023.4534	−12	74...	73	13951.3110 a	48	64....	65	13843.3548	−38	44....	44	13969.0970 a	31
5....	4	14024.2597	4	76...	75	13945.1050 a	−14	65....	66	13838.8316	−78	45....	45	13966.7496	−20
6....	5	14025.0136	0	78...	77	13938.6430 a	−127	66....	67	13834.2628	11	46....	46	13964.3535	−4
7....	6	14025.7165	−10	83...	82	13921.3940 a	−243	67....	68	13829.6210	−42	47....	47	13961.9034	28
8....	7	14026.3683	−27	84...	83	13917.7820 a	34	68....	69	13824.9261	−36	48....	48	13959.3899	−16
9....	8	14026.9748	9	87...	86	13906.4520 a	−187	69....	70	13820.1647	−104	49....	49	13956.8242	−22
10...	9	14027.5282	20	88...	87	13902.5880 a	170	70....	71	13815.3630 a	20	50....	50	13954.2053	2
11...	10	14028.0292	13	89...	88	13898.6170 a	113	71....	72	13810.4840 a	−35	51....	51	13951.5244	−31
12...	11	14028.4796	7	5....	6	14012.6468	24	74....	75	13795.5080 a	5	52....	52	13948.7959	27
13...	12	14028.8815	24	6....	7	14011.2886	15	75....	76	13790.4090 a	152	53....	53	13946.0011	−12
14...	13	14029.2363	80	7....	8	14009.8872	76	76....	77	13785.2250 a	55	54....	54	13943.1525	−18
15...	14	14029.5290	23	8....	9	14008.4184	−34	77....	78	13779.9900 a	55	55....	55	13940.2445	−47
16...	15	14029.7739	0	10...	11	14005.3538	−12	79....	80	13769.3450 a	136	56....	56	13937.2852	−14
17...	16	14029.9654	−45	11...	12	14003.7449	−10	85....	86	13735.9010 a	78	57....	57	13934.2665	−1
18...	17	14030.1150	3	12...	13	14002.0894	30	87....	88	13724.2510 a	22	58....	58	13931.1868	−20
19...	18	14030.2024	−55	13...	14	14000.3775	12	88....	89	13718.3360 a	38	59....	59	13928.0517	−13
22...	21	14030.1764	−18	14...	15	13998.6178	23	91....	92	13700.2090 a	67	60....	60	13924.8559	−31
23...	22	14030.0628	−19	15...	16	13996.8018	−23	93....	94	13687.8010 a	41	61....	61	13921.6038	−29
24...	23	14029.9001	11	16...	17	13994.9414	−5	96....	97	13668.7180 a	117	62....	62	13918.2941	−16
25...	24	14029.6813	1	17...	18	13993.0282	−6	98....	99	13655.6540 a	−12	63....	63	13914.8974	−28
26...	25	14029.4085	−26	18...	19	13991.0688	39	99....	100	13649.0390 a	73	64....	64	13911.4941	−31
27...	26	14029.0884	0	19...	20	13989.0509	11	100...	101	13642.3620 a	194	65....	65	13908.0058	−34
28...	27	14028.7157	26	20...	21	13986.9794	−42	101...	102	13635.5880 a	2	67....	67	13900.8553	5
29...	28	14028.2887	36	21...	22	13984.8732	70	104...	105	13614.9370 a	105	68....	68	13897.1862	−18
30...	29	14027.8047	8	22...	23	13982.6982	8	105...	106	13607.8970 a	−94	69....	69	13893.4679	69
31...	30	14027.2687	−10	23...	24	13980.4801	29	106...	107	13600.8390 a	196	70....	70	13889.6880	141
32...	31	14026.6825	2	24...	25	13978.2013	−41	5.....	5	14018.9821	24	71....	71	13885.8289	26
33...	32	14026.0397	−16	25...	26	13975.8828	9	6.....	6	14018.6806	24	72....	72	13881.9143	−36
34...	33	14025.3483	15	26...	27	13973.5065	−1	7.....	7	14018.3267	3	73....	73	13877.9417	−71
35...	34	14024.5931	−52	27...	28	13971.0740	−54	8.....	8	14017.9208	−34	74....	74	13873.9220	36
36...	35	14023.7960	1	28...	29	13968.6020	19	9.....	9	14017.4690	−24	75....	75	13869.8163	−10
37...	36	14022.9377	−16	29...	30	13966.0680	−5	10....	10	14016.9723	40	76....	76	13865.6611	−12
38...	37	14022.0270 a	−13	30...	31	13963.5020 a	173	11....	11	14016.4165	20	77....	77	13861.4561	−24
39...	38	14021.0611	−17	31...	32	13960.8484	−0	12....	12	14015.8119	17	78....	78	13857.1705	−11
40...	39	14020.0421	−4	32...	33	13958.1578	−17	13....	13	14015.1535	−17	79....	79	13852.8457	32
41...	40	14018.9704	31	33...	34	13955.4179	1	14....	14	14014.4505	11	80....	80	13848.4467	57
42...	41	14017.8403	34	34...	35	13952.6226	−5	15....	15	14013.6940	12	81....	81	13843.9815	47
43...	42	14016.6484	−29	35...	36	13949.7753	−2	16....	16	14012.8855	3	82....	82	13839.4464	−34
44...	43	14015.4093	−7	36...	37	13946.8730	−16	17....	17	14012.0284	18	83....	83	13834.8569	−28
45...	44	14014.1186	56	37...	38	13943.9203	−1	18....	18	14011.1164	−5	84....	84	13830.2090 a	27
46...	45	14012.7578	−24	38...	39	13940.9130	5	19....	19	14010.1547	−12	85....	85	13825.4910 a	16
47...	46	14011.3485	−26	39...	40	13937.8497	−14	20....	20	14009.1445	9	86....	86	13820.7120 a	32
48...	47	14009.8860 a	3	40...	41	13934.7356	−2	21....	21	14008.0815	16	87....	87	13815.8632	−10
49...	48	14008.3561	−77	41...	42	13931.5663	−1	22....	22	14006.9557	−88	88....	88	13810.9560 a	5
50...	49	14006.7794	−57	42...	43	13928.3422	−7	23....	23	14005.7980	5	89....	89	13805.9745	−79
51...	50	14005.1495	1	43...	44	13925.0630	−19	24....	24	14004.5820	34	90....	90	13800.9506	59
52...	51	14003.4569	3	44...	45	13921.7281	−44	25....	25	14003.3093	14	91....	91	13795.8448	29
53...	52	14001.6991	−72	45...	46	13918.3453	−1	26....	26	14001.9889	39	93....	93	13785.4440 a	27
54...	53	13999.9040	55	46...	47	13914.9106	72	27....	27	14000.6100	1	94....	94	13780.1510 a	83
55...	54	13998.0296	−32	47...	48	13911.4043	−20	28....	28	13999.1821	−4	96....	96	13769.3450 a	−31
56...	55	13996.1100	9	48...	49	13907.8505	−36	29....	29	13997.7010	−15	99....	99	13752.6440 a	−14
57...	56	13994.1223	−48	49...	50	13904.2451	−13	30....	30	13996.1698	−2	100...	100	13746.9680 a	58
58...	57	13992.0867	0	50...	51	13900.5817	−14	31....	31	13994.5848	3	102...	102	13735.3740 a	67
59...	58	13989.9864	−12	51...	52	13896.8613	−28	32....	32	13992.9463	1	103...	103	13729.4700 a	15
60...	59	13987.8213	−82	52...	53	13893.0930	39	33....	33	13991.2544	−3	105...	105	13717.4640 a	−30
61...	60	13985.6069	−54	53...	54	13889.2548	−32	34....	34	13989.5095	−4	106...	106	13711.3590 a	−48
62...	61	13983.3275	−82	54...	55	13885.3715	9	35....	35	13987.7118	2	107...	107	13705.2110 a	189
63...	62	13981.0022	25	55...	56	13881.4212	−55	36....	36	13985.8589	−8	108...	108	13698.9490 a	−25
64...	63	13978.5972	−65	56...	57	13877.4252	−10	37....	37	13983.9525	−16	109...	109	13692.6520 a	101
65...	64	13976.1435	−43	57...	58	13873.3653	−34	38....	38	13981.9931	−14				
68...	67	13968.4160 a	−16	59...	60	13865.0768	−57	39....	39	13979.9809	1				
69...	68	13965.7370 a	176	60...	61	13860.8508	−25	40....	40	13977.9160 a	32				
70...	69	13962.9670 a	71	61...	62	13856.5763	98	41....	41	13975.7910 a	8				
71...	70	13960.1270 a	−121	62...	63	13852.2251	31	42....	42	13973.6180 a	49				

TABLE 1—*Continued*

J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$
							$A\,^3\Phi_3$–$X\,^3\Delta_2$ 0–0								
4	3	14099.5526	−138	78	77	14000.1020 a	36	55	56	13948.2520 a	−37	34	34	14061.9240	−3
5	4	14100.3482	−17	79	78	13996.4850 a	20	57	58	13939.6468	54	35	35	14059.9218	−6
6	5	14101.0765	1	80	79	13992.8010 a	−26	58	59	13935.2550 a	92	36	36	14057.8624	−2
7	6	14101.7436	−23	82	81	13985.2630 a	109	59	60	13930.7878	−34	37	37	14055.7443	−7
8	7	14102.3568	−16	83	82	13981.3810 a	14	60	61	13926.2669	−106	38	38	14053.5688	−4
9	8	14102.9141	4	84	83	13977.4510 a	86	62	63	13917.0783	60	39	39	14051.3347	−9
10	9	14103.4122	2	86	85	13969.3750 a	20	63	64	13912.3780	−25	40	40	14049.0433	−4
11	10	14103.8524	−8	87	86	13965.2440 a	36	64	65	13907.6207	−84	41	41	14046.6927	−9
12	11	14104.2343	−28	88	87	13961.0520 a	97	65	66	13902.8182	1	42	42	14044.2856	4
13	12	14104.5614	−25	91	90	13948.0540 a	8	66	67	13897.9490 a	17	43	43	14041.8180 a	−6
14	13	14104.8353	17	92	91	13943.5900 a	−11	72	73	13867.4610 a	16	44	44	14039.2967	33
15	14	14105.0449	−10	93	92	13939.0560 a	−65	74	75	13856.8120 a	−7	45	45	14036.7108	10
16	15	14105.1985	−24	94	93	13934.4630 a	−42	75	76	13851.4000 a	20	46	46	14034.0681	6
19	18	14105.3219	−0	95	94	13929.8110 a	60	76	77	13845.9250 a	29	47	47	14031.3713	47
20	19	14105.2465	−9	99	98	13910.4850 a	24	77	78	13840.3850 a	0	48	48	14028.6035	−35
21	20	14105.1145	−9	100	99	13905.4730 a	−95	79	80	13829.1270 a	6	49	49	14025.7901	16
22	21	14104.9250	−8	102	101	13895.2820 a	46	81	82	13817.6210 a	−1	50	50	14022.9134	24
23	22	14104.6809	22	104	103	13884.7990 a	15	82	83	13811.7760 a	5	51	51	14019.9708	−36
24	23	14104.3731	−8	109	108	13857.3850 a	14	83	84	13805.8640 a	−38	52	52	14016.9723	−64
25	24	14104.0144	29	110	109	13851.6760 a	−148	85	86	13793.8460 a	−192	53	53	14013.9336	98
26	25	14103.5902	−10	5	6	14088.6007	−0	86	87	13787.7700 a	−0	54	54	14010.8108	13
27	26	14103.1120	−11	6	7	14087.2008	94	87	88	13781.5900 a	−221	55	55	14007.6370	12
28	27	14102.5762	−11	7	8	14085.7247	−5	89	90	13769.1070 a	−1	56	56	14004.4047	22
29	28	14101.9836	1	8	9	14084.1810	−213	90	91	13762.7790 a	193	57	57	14001.1110	15
30	29	14101.3311	−6	9	10	14082.6247	22	91	92	13756.3470 a	−19	58	58	13997.7559	−9
31	30	14100.6224	5	10	11	14080.9838	−21	92	93	13749.8760 a	16	59	59	13994.3448	6
32	31	14099.8534	−6	11	12	14079.2934	8	93	94	13743.3350 a	−10	60	60	13990.8750	34
33	32	14099.0262	−17	12	13	14077.5401	−22	94	95	13736.7330 a	−7	61	61	13987.3427	39
34	33	14098.1518	82	13	14	14075.7340	−13	96	97	13723.3190 a	−172	62	62	13983.7425	−33
35	34	14097.2009	−0	14	15	14073.8712	−4	97	98	13716.5450 a	43	63	63	13980.0923	−0
36	35	14096.2003	4	15	16	14071.9508	−2	98	99	13709.6690 a	−114	64	64	13976.3739	−45
37	36	14095.1401	−2	16	17	14069.9706	−29	99	100	13702.7510 a	−42	65	65	13972.6035	−3
38	37	14094.0238	15	17	18	14067.9382	−10	100	101	13695.7530 a	−119	66	66	13968.7669	−16
39	38	14092.8465	9	18	19	14065.8455	−27	103	104	13674.3960 a	−52	67	67	13964.8810 a	87
40	39	14091.6133	31	19	20	14063.6991	−10	104	105	13667.1420 a	−63	68	68	13960.9134	−16
41	40	14090.3173	12	20	21	14061.4939	−15	106	107	13652.4380 a	−60	69	69	13956.8973	7
42	41	14088.9645	15	21	22	14059.2326	−11	107	108	13644.9830 a	−92	70	70	13952.8174	5
43	42	14087.5512	2	22	23	14056.9156	6	108	109	13637.4660 a	−76	71	71	13948.6770 a	14
44	43	14086.0830	31	23	24	14054.5387	−9	109	110	13629.8810 a	−71	72	72	13944.4759	30
45	44	14084.5496	0	24	25	14052.1075	3	4	4	14095.2893	−45	75	75	13931.4886	−48
46	45	14082.9632	32	25	26	14049.6182	4	5	5	14095.0087	−5	76	76	13927.0473	47
47	46	14081.3101	−11	26	27	14047.0709	−5	6	6	14094.6692	14	77	77	13922.5223	−72
48	47	14079.6011	−18	27	28	14044.4676	−5	7	7	14094.2659	−36	78	78	13917.9447	−92
49	48	14077.8369	20	29	30	14039.0895	−7	8	8	14093.8109	−33	79	79	13913.3112	−44
50	49	14076.0057	−16	30	31	14036.3170	14	9	9	14093.3009	−10	80	80	13908.6132	−12
51	50	14074.1206	6	31	32	14033.4830	−10	10	10	14092.7329	2	81	81	13903.8570	68
52	51	14072.1749	21	32	33	14030.5933	−18	11	11	14092.1068	3	82	82	13899.0176	−53
53	52	14070.1663	8	33	34	14027.6600	109	12	12	14091.4250	17	83	83	13894.1308	−14
54	53	14068.0933	−48	34	35	14024.6459	2	13	13	14090.6823	−8	85	85	13884.1571	−29
55	54	14065.9696	−9	35	36	14021.5856	5	14	14	14089.8854	−5	86	86	13879.0845	63
56	55	14063.7828	3	36	37	14018.4666	−6	15	15	14089.0311	−5	87	87	13873.9299	−24
58	57	14059.2260 a	10	37	38	14015.2901	−18	16	16	14088.1196	−6	88	88	13868.7291	70
59	58	14056.8589	37	38	39	14012.0655	64	17	17	14087.1516	−3	89	89	13863.4563	87
60	59	14054.4171	−74	39	40	14008.7693	4	18	18	14086.1270	6	90	90	13858.1090 a	6
61	60	14051.9376	48	40	41	14005.4207	−6	19	19	14085.0433	−4	91	91	13852.7020 a	−25
62	61	14049.3808	9	41	42	14002.0233	75	20	20	14083.9037	−1	92	92	13847.2390 a	35
64	63	14044.0928	26	42	43	13998.5527	−1	21	21	14082.7059	−10	93	93	13841.6990 a	−24
65	64	14041.3542	11	43	44	13995.0301	−21	22	22	14081.4526	−1	95	95	13830.4380 a	12
66	65	14038.5605	62	44	45	13991.4506	−30	23	23	14080.1413	2	96	96	13824.7040 a	−20
67	66	14035.6948	12	45	46	13987.8182	9	24	24	14078.7717	−6	98	98	13813.0490 a	28
68	67	14032.7712	3	46	47	13984.1242	12	25	25	14077.3452	−10	101	101	13795.0600 a	18
69	68	14029.7739	−121	47	48	13980.3699	−8	26	26	14075.8621	−7	103	103	13782.7320 a	5
70	69	14026.7421	33	48	49	13976.5672	68	27	27	14074.3220	2	104	104	13776.4660 a	−11
71	70	14023.6217	−74	49	50	13972.6973	54	28	28	14072.7233	−2	105	105	13770.1350 a	−1
72	71	14020.4560 a	−8	50	51	13968.7669	16	29	29	14071.0674	−3	106	106	13763.7320 a	−32
73	72	14017.2220 a	2	51	52	13964.7762	−41	30	30	14069.3539	−4	107	107	13757.2630 a	−43
75	74	14010.5710 a	85	52	53	13960.7300	−69	31	31	14067.5829	−4	108	108	13750.7270 a	−40
76	75	14007.1400 a	20	53	54	13956.6346	−5	32	32	14065.7550	4				
77	76	14003.6660 a	160	54	55	13952.4770	23	33	33	14063.8677	−6				

TABLE 1—*Continued*

J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$
							$A\,^3\Phi_4$–$X\,^3\Delta_3$ 0–0								
19…	18	14171.8573	−13	76…	75	14064.0550 a	103	56…	57	14004.1550	−9	38…	38	14117.5507	7
20…	19	14171.7017	−30	77…	76	14060.3180 a	−102	57…	58	13999.6093	15	39…	39	14115.1576	6
21…	20	14171.4895	4	78…	77	14056.5540 a	69	59…	60	13990.3317	24	40…	40	14112.7036	9
22…	21	14171.2106	−12	79…	78	14052.7000 a	−13	60…	61	13985.5971	−17	41…	41	14110.1879	7
23…	22	14170.8687	−40	81…	80	14044.8140 a	−10	61…	62	13980.8060	−14	42…	42	14107.6106	2
24…	23	14170.4720	0	82…	81	14040.7980 a	238	62…	63	13975.9509	−42	43…	43	14104.9749	24
25…	24	14170.0056	−39	88…	87	14015.1540 a	4	64…	65	13966.0680	6	44…	44	14102.2746	14
26…	25	14169.4827	−26	91…	90	14001.4260 a	−258	65…	66	13961.0282	−38	45…	45	14099.5101	−25
27…	26	14168.8971	−22	14…	15	14140.4375	2	66…	67	13955.9347	−6	46…	46	14096.6913	5
28…	27	14168.2492	−24	15…	16	14138.4416	30	67…	68	13950.7770 a	−5	47…	47	14093.8109	33
29…	28	14167.5400	−21	17…	18	14134.2527	−50	73…	74	13918.5290 a	−115	48…	48	14090.8644	13
30…	29	14166.7686	−23	18…	19	14132.0759	3	77…	78	13895.8070 a	−79	49…	49	14087.8593	21
31…	30	14165.9382	4	19…	20	14129.8259	−68	85…	86	13847.3980 a	247	50…	50	14084.7876	−24
32…	31	14165.0438	7	20…	21	14127.5292	6	86…	87	13841.0180 a	−175	51…	51	14081.6614	2
33…	32	14164.0875	10	21…	22	14125.1649	13	6….	6	14161.7701	−40	52…	52	14078.4696	−14
34…	33	14163.0691	10	22…	23	14122.7358	−18	7….	7	14161.3399	−36	53…	53	14075.2163	−31
35…	34	14161.9915	35	23…	24	14120.2509	1	8….	8	14160.8481	−34	54…	54	14071.9061	−1
36…	35	14160.8481	21	24…	25	14117.7027	−4	9….	9	14160.2965	−15	55…	55	14068.5318	5
37…	36	14159.6473	52	25…	26	14115.0944	−2	11…	11	14159.0060	−5	56…	56	14065.0992	42
38…	37	14158.3766	3	26…	27	14112.4239	−13	12…	12	14158.2685	−1	57…	57	14061.5963	−6
39…	38	14157.0495	8	27…	28	14109.6920	−30	13…	13	14157.4697	5	58…	58	14058.0357	−14
40…	39	14155.6639	48	28…	29	14106.9038	−3	14…	14	14156.6079	−4	59…	59	14054.4171	15
41…	40	14154.2087	10	29…	30	14104.0583	58	15…	15	14155.6780	−81	60…	60	14050.7331	9
42…	41	14152.6973	30	30…	31	14101.1386	−15	16…	16	14154.7022	−3	61…	61	14046.9883	14
43…	42	14151.1188	−2	31…	32	14098.1744	73	17…	17	14153.6570	−5	62…	62	14043.1795	−3
44…	43	14149.4868	52	32…	33	14095.1366	32	18…	18	14152.5507	−3	63…	63	14039.2967	−13
45…	44	14147.7859	37	33…	34	14092.0408	18	19…	19	14151.3839	7	64…	64	14035.3813	21
46…	45	14146.0254	48	34…	35	14088.8859	18	20…	20	14150.1543	2	67…	67	14023.2120 a	−0
47…	46	14144.1964	−7	35…	36	14085.6697	12	21…	21	14148.8628	−8	69…	69	14014.7660 a	−22
48…	47	14142.3108	−6	36…	37	14082.3954	30	22…	22	14147.5114	−3	71…	71	14006.0990 a	−16
49…	48	14140.3618	−17	37…	38	14079.0577	21	23…	23	14146.0963	−23	73…	73	13997.1940 a	32
50…	49	14138.3559	26	38…	39	14075.6602	18	24…	24	14144.6239	−3	74…	74	13992.6280 a	−62
52…	51	14134.1433	−30	39…	40	14072.1957	−49	25…	25	14143.0887	3	75…	75	13988.0160 a	14
53…	52	14131.9479	−12	40…	41	14068.6834	12	26…	26	14141.4915	1	77…	77	13978.5950 a	93
54…	53	14129.6887	−10	41…	42	14065.0992	−42	27…	27	14139.8332	1	78…	78	13973.7790 a	27
55…	54	14127.3678	1	42…	43	14061.4709	69	28…	28	14138.1136	1	79…	79	13968.9060 a	26
56…	55	14124.9842	11	43…	44	14057.7672	32	29…	29	14136.3378	50	81…	81	13958.9640 a	−25
57…	56	14122.5354	−6	44…	45	14054.0015	−22	30…	30	14134.4910	4	85…	85	13938.3100 a	−15
58…	57	14120.0259	−4	45…	46	14050.1857	30	31…	31	14132.5884	10	86…	86	13933.0030 a	−16
59…	58	14117.4519	−18	46…	47	14046.2860	−153	32…	32	14130.6227	−1	87…	87	13927.6310 a	118
60…	59	14114.8207	22	47…	48	14042.3599	5	33…	33	14128.5960	−11	88…	88	13922.1580 a	−11
61…	60	14112.1169	−35	48…	49	14038.3572	3	34…	34	14126.5106	5	89…	89	13916.6370 a	−17
62…	61	14109.3555	−38	49…	50	14034.2934	−4	35…	35	14124.3649	30	90…	90	13911.0650 a	−91
63…	62	14106.5297	−54	51…	52	14025.9767	−94	36…	36	14122.1525	−0	92…	92	13899.7030 a	−15
74…	73	14071.2660 a	−185	52…	53	14021.7413	1	37…	37	14119.8819	0	93…	93	13893.9250 a	−17
							$A\,^3\Phi_2$–$X\,^3\Delta_1$ 0–1								
10…	9	13027.7747	53	35…	34	13028.1179	−33	58…	57	13001.9519	−97	27…	28	12973.4837	104
11…	10	13028.3292	−14	36…	35	13027.5226	−54	59…	58	13000.2168	46	28…	29	12971.1643	−28
12…	11	13028.8463	−7	37…	36	13026.8835	−32	60…	59	12998.4080 a	−20	29…	30	12968.8160	13
13…	12	13029.3226	40	38…	37	13026.2042	71	61…	60	12996.5530 a	−18	30…	31	12966.4058	−10
14…	13	13029.7416	−36	39…	38	13025.4592	2	68…	67	12982.0700 a	16	31…	32	12963.9735	26
15…	14	13030.1207	−61	40…	39	13024.6695	−27	69…	68	12979.7760 a	−60	32…	33	12961.4742	−50
16…	15	13030.4654	21	41…	40	13023.8281	−84	8….	9	13008.6606	−42	33…	34	12958.9469	62
17…	16	13030.7599	53	42…	41	13022.9488	−30	9….	10	13007.2142	−20	34…	35	12956.3543	−10
18…	17	13030.9923	−82	43…	42	13022.0106	−72	10…	11	13005.7169	−61	35…	36	12953.7252	22
19…	18	13031.1983	−26	44…	43	13021.0340	−3	11…	12	13004.1850 a	−4	36…	37	12951.0411	−23
20…	19	13031.3559	0	45…	44	13020.0059	47	13…	14	13000.9815	51	37…	38	12948.3225	59
21…	20	13031.4633	−18	46…	45	13018.9120	−62	14…	15	12999.3068	18	38…	39	12945.5428	5
24…	23	13031.5287	110	47…	46	13017.7808	−44	15…	16	12997.5828	−59	39…	40	12942.7233	30
25…	24	13031.4427	−2	48…	47	13016.6012	−8	16…	17	12995.8289	12	40…	41	12939.8513	6
26…	25	13031.3266	48	49…	48	13015.3617	−66	17…	18	12994.0220 a	1	41…	42	12936.9293	−36
27…	26	13031.1515	−27	50…	49	13014.0903	62	18…	19	12992.1725	15	42…	43	12933.9662	−10
28…	27	13030.9444	44	51…	50	13012.7437	−52	20…	21	12988.3389	49	43…	44	12930.9470	−61
29…	28	13030.6691	−99	52…	51	13011.3583	−44	21…	22	12986.3452	−24	44…	45	12927.8828	−78
30…	29	13030.3687	−23	53…	52	13009.9166	−86	22…	23	12984.3118	−42	45…	46	12924.7921	126
31…	30	13030.0105	−55	54…	53	13008.4459	97	23…	24	12982.2448	60	46…	47	12921.6191	−6
32…	31	13029.6076	−60	55…	54	13006.8881	−75	24…	25	12980.1159	−2	47…	48	12918.4105	−4
33…	32	13029.1619	−19	56…	55	13005.3026	−5	25…	26	12977.9399	−78	48…	49	12915.1720 a	190
34…	33	13028.6670	6	57…	56	13003.6567	−17	26…	27	12975.7322	−13	49…	50	12911.8490 a	32

TABLE 1—*Continued*

J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$
50…	51	12908.4850 a	−42	16…	16	13013.6730 a	32	39…	39	12984.6093	−12	63…	63	12926.9961	42
51…	52	12905.1030 a	201	17…	17	13012.9107	−18	40…	40	12982.7798	−23	64…	64	12923.9489	−11
54…	55	12894.5890 a	244	18…	18	13012.1101	2	41…	41	12980.9049	−2	65…	65	12920.8479	−73
55…	56	12890.9660 a	79	19…	19	13011.2595	−26	42…	42	12978.9735	−60	66…	66	12917.7045	−26
56…	57	12887.3270 a	260	20…	20	13010.3693	4	43…	43	12976.9977	−76	67…	67	12914.5040 a	−16
57…	58	12883.5810 a	−123	21…	21	13009.4277	−26	45…	45	12972.9913	16	68…	68	12911.2500 a	−6
59…	60	12876.0320 a	70	22…	22	13008.4459	−1	46…	46	12970.7884	4	69…	69	12907.9400 a	−17
61…	62	12868.2760 a	242	23…	23	13007.4151	−10	47…	47	12968.6139	−30	70…	70	12904.5840 a	51
62…	63	12864.2900 a	21	24…	24	13006.3399	−5	48…	48	12966.4038	78	71…	71	12901.1720 a	102
64…	65	12856.1830 a	−215	25…	25	13005.2175	−11	49…	49	12964.1261	8	72…	72	12897.6840 a	−63
65…	66	12852.0930 a	84	26…	26	13004.0482	−26	50…	50	12961.7981	−64	73…	73	12894.1680 a	38
4….	4	13019.2785	125	27…	27	13002.8371	2	51…	51	12959.4319	−16	74…	74	12890.5810 a	−23
5….	5	13019.0569	124	28…	28	13001.5743	−22	52…	52	12957.0094	−26	75…	75	12886.9470 a	−4
6….	6	13018.7848	62	29…	29	13000.2680	−17	53…	53	12954.5370	−30	76…	76	12883.2410 a	−15
7….	7	13018.4733	49	30…	30	12998.9130	−31	54…	54	12952.0121	−49	78…	78	12875.7070 a	−2
8….	8	13018.1091	−47	31…	31	12997.5146	−12	55…	55	12949.4470 a	38	81…	81	12863.9670 a	26
9….	9	13017.7193	47	32…	32	12996.0675	−12	56…	56	12946.8150 a	−30	82…	82	12859.9350 a	−24
10…	10	13017.2665	−44	33…	33	12994.5721	−22	57…	57	12944.1383	−32	83…	83	12855.8630 a	94
11…	11	13016.7812	−15	34…	34	12993.0298	−29	58…	58	12941.4084	−50	84…	84	12851.7630 a	500
12…	12	13016.2468	−29	35…	35	12991.4424	−14	59…	59	12938.6339	5	85…	85	12847.5170 a	17
13…	13	13015.6737	16	36…	36	12989.8007	−66	60…	60	12935.7990	−26	86…	86	12843.2620 a	18
14…	14	13015.0520 a	35	37…	37	12988.1235	5	61…	61	12932.9177	3	88…	88	12834.5950 a	179
15…	15	13014.3827	5	38…	38	12986.3883	−25	62…	62	12929.9730	−79	89…	89	12830.1620 a	133

$A\,^3\Phi_3$–$X\,^3\Delta_2$ 0–1

J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$
4….	3	13099.5648	36	54…	53	13076.7945	−47	45…	46	12994.3757	0	29…	29	13073.6757	−30
5….	4	13100.3586	−105	56…	55	13073.1476	−40	46…	47	12990.9654	−34	30…	30	13072.1486	1
6….	5	13101.1261	1	57…	56	13071.2526	62	47…	48	12987.5040	−64	31…	31	13070.5698	30
7….	6	13101.8271	−50	58…	57	13069.2821	−48	48…	49	12983.9983	−117	32…	32	13068.9347	12
8….	7	13102.4875	3	60…	59	13065.1989	−50	49…	50	12980.4343	−33	33…	33	13067.2521	35
9….	8	13103.0944	31	61…	60	13063.0779	−25	50…	51	12976.8239	7	34…	34	13065.5097	−24
10…	9	13103.6421	−23	64…	63	13056.3770 a	−28	51…	52	12973.1590	23	35…	35	13063.7241	1
11…	10	13104.1550	84	66…	65	13051.6370 a	7	52…	53	12969.4472	92	36…	36	13061.8835	−7
12…	11	13104.5958	−18	68…	67	13046.6760 a	55	53…	54	12965.6677	6	37…	37	13059.9904	−20
13…	12	13105.0000	24	71…	70	13038.8010 a	−12	55…	56	12957.9700 a	20	38…	38	13058.0467	−23
14…	13	13105.3473	9	72…	71	13036.0680 a	10	57…	58	12950.0620 a	32	39…	39	13056.0548	13
15…	14	13105.6441	−0	76…	75	13024.5620 a	26	58…	59	12946.0310 a	58	40…	40	13054.0036	−25
16…	15	13105.8972	66	78…	77	13018.4670 a	35	59…	60	12941.9360 a	−28	41…	41	13051.9064	−2
17…	16	13106.0928	70	81…	80	13008.8820 a	−60	61…	62	12933.6190 a	118	42…	42	13049.7524	−26
18…	17	13106.2323	25	82…	81	13005.5810 a	5	62…	63	12929.3610 a	−8	43…	43	13047.5525	13
21…	20	13106.3550	12	85…	84	12995.3100 a	20	63…	64	12925.0660 a	29	44…	44	13045.2945	−7
22…	21	13106.2998	75	86…	85	12991.7640 a	−27	67…	68	12907.3310 a	−33	45…	45	13042.9866	−1
23…	22	13106.1805	11	89…	88	12980.7850 a	−37	70…	71	12893.4560 a	−176	46…	46	13040.6242	−17
24…	23	13106.0121	−28	12…	13	13078.0563	10	72…	73	12883.9680 a	54	47…	47	13038.2119	−6
25…	24	13105.7977	−11	13…	14	13076.3299	−36	73…	74	12879.1260 a	4	48…	48	13035.7451	−15
26…	25	13105.5333	22	14…	15	13074.5626	13	74…	75	12874.2230 a	−111	49…	49	13033.2227	−53
27…	26	13105.2140	23	15…	16	13072.7385	3	77…	78	12859.2280 a	−33	50…	50	13030.6691	126
28…	27	13104.8428	22	16…	17	13070.8615	−28	4….	4	13095.3071	−59	51…	51	13028.0312	−11
29…	28	13104.4184	8	17…	18	13068.9347	−52	5….	5	13095.0588	−0	52…	52	13025.3563	12
30…	29	13103.9434	6	18…	19	13066.9580	−66	6….	6	13094.7548	8	53…	53	13022.6202	−47
31…	30	13103.4156	−5	19…	20	13064.9412	25	7….	7	13094.3969	−14	54…	54	13019.8342	−72
32…	31	13102.8381	6	20…	21	13062.8609	−10	8….	8	13093.9877	−41	55…	55	13017.0039	−9
33…	32	13102.2079	13	22…	23	13058.5532	−29	9….	9	13093.5369	26	56…	56	13014.1140 a	−8
34…	33	13101.5225	−13	23…	24	13056.3245	−25	10…	10	13093.0228	−33	57…	57	13011.1659	−54
35…	34	13100.7903	16	24…	25	13054.0452	−19	11…	11	13092.4640	−29	58…	58	13008.1721	−22
36…	35	13100.0033	18	25…	26	13051.7175	12	12…	12	13091.8557	−12	59…	59	13005.1188	−48
37…	36	13099.1616	−3	26…	27	13049.3385	38	13…	13	13091.1975	16	60…	60	13002.0155	−36
38…	37	13098.2681	−17	27…	28	13046.9009	−12	14…	14	13090.4881	40	61…	61	12998.8569	−39
39…	38	13097.3301	48	28…	29	13044.4199	12	15…	15	13089.7273	61	62…	62	12995.6438	−46
40…	39	13096.3294	12	29…	30	13041.8855	11	16…	16	13088.9072	−3	63…	63	12992.3850 a	32
41…	40	13095.2779	−6	30…	31	13039.2939	−52	17…	17	13088.0402	−25	64…	64	12989.0600 a	−11
42…	41	13094.1741	−18	31…	32	13036.6623	−4	18…	18	13087.1278	8	66…	66	12982.2560 a	−2
43…	42	13093.0228	21	32…	33	13033.9840 a	86	19…	19	13086.1610	9	68…	68	12975.2380 a	51
44…	43	13091.8130	5	34…	35	13028.4492	19	20…	20	13085.1436	13	69…	69	12971.6390 a	1
45…	44	13090.5532	19	35…	36	13025.6103	36	21…	21	13084.0732	−2	70…	70	12967.9910 a	10
46…	45	13089.2320	−50	37…	38	13019.7779	63	22…	22	13082.9473	−60	71…	71	12964.2880 a	22
47…	46	13087.8708	13	38…	39	13016.7812	40	23…	23	13081.7798	−24	72…	72	12960.5250 a	−14
48…	47	13086.4470	−18	39…	40	13013.7306	−8	24…	24	13080.5616	19	73…	73	12956.7150 a	35
50…	49	13083.4491	22	41…	42	13007.4826	−30	25…	25	13079.2843	−18	74…	74	12952.8420 a	10
51…	50	13081.8690	33	42…	43	13004.2825	−10	26…	26	13077.9615	2	75…	75	12948.9050 a	−98
52…	51	13080.2326	19	43…	44	13001.0389	50	27…	27	13076.5857	6	76…	76	12944.9330 a	3
53…	52	13078.5421	1	44…	45	12997.7300	−6	28…	28	13075.1585	9	79…	79	12932.6520 a	24

TABLE 1—*Continued*

J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$
80…	80	12928.4460 a	36	84…	84	12911.0400 a	−58	89…	89	12888.0070 a	−23	96…	96	12853.3120 a	19
81…	81	12924.1820 a	33	85…	85	12906.5540 a	2	91…	91	12878.4000 a	112	97…	97	12848.1090 a	−77
82…	82	12919.8590 a	9	87…	87	12897.4020 a	48	94…	94	12863.5140 a	−46	98…	98	12842.8520 a	−11
83…	83	12915.4810 a	5	88…	88	12892.7290 a	−32	95…	95	12858.4310 a	−130				
							$A\,{}^3\Phi_4$–$X\,{}^3\Delta_3$ 0–1								
5….	4	13167.5401	−91	50…	49	13145.9144	−68	47…	48	13049.6233	9	35…	35	13128.2297	9
6….	5	13168.2861	−35	51…	50	13144.1589	−12	48…	49	13045.9185	−63	36…	36	13126.2434	1
7….	6	13168.9668	−79	52…	51	13142.3405	−22	49…	50	13042.1797	68	37…	37	13124.2050	23
8….	7	13169.6049	4	61…	60	13123.4300 a	−256	50…	51	13038.3856	189	38…	38	13122.1030	−42
9….	8	13170.1741	−46	66…	65	13110.9640 a	−186	51…	52	13034.5010	−53	39…	39	13119.9559	−8
10…	9	13170.6985	9	74…	73	13088.0560 a	25	52…	53	13030.5967	53	40…	40	13117.7511	−1
11…	10	13171.1609	−1	9….	10	13149.8121	65	53…	54	13026.6350 a	127	41…	41	13115.4930	24
12…	11	13171.5687	−3	10…	11	13148.1836	24	65…	66	12974.7130 a	−294	42…	42	13113.1739	−12
13…	12	13171.9194	−21	11…	12	13146.5019	1	67…	68	12965.3120 a	−181	43…	43	13110.8047	1
14…	13	13172.2211	25	12…	13	13144.7624	−50	4….	4	13162.4557	−75	44…	44	13108.3832	42
15…	14	13172.4587	−15	13…	14	13142.9700	−79	5….	5	13162.1856	−11	45…	45	13105.8972	−12
16…	15	13172.6483	19	14…	15	13141.1354	19	6….	6	13161.8522	−28	46…	46	13103.3579	−48
22…	21	13172.6003	22	15…	16	13139.2345	3	7….	7	13161.4691	12	47…	47	13100.7804	85
23…	22	13172.3963	5	16…	17	13137.2897	96	8….	8	13161.0280	24	48…	48	13098.1259	−2
24…	23	13172.1370	−10	17…	18	13135.2657	−53	9….	9	13160.5266	−14	49…	49	13095.4253	1
25…	24	13171.8279	32	18…	19	13133.2085	14	10…	10	13159.9730	−22	50…	50	13092.6703	12
26…	25	13171.4544	−16	20…	21	13128.9170	21	11…	11	13159.3606	−64	51…	51	13089.8605	28
27…	26	13171.0267	−49	21…	22	13126.6837	−29	12…	12	13158.6998	−39	52…	52	13086.9912	−1
28…	27	13170.5515	−2	22…	23	13124.4054	17	13…	13	13157.9919	68	53…	53	13084.0732	37
29…	28	13170.0160	−3	24…	25	13119.6768	30	14…	14	13157.2111	−3	54…	54	13081.0980	55
30…	29	13169.4243	−11	25…	26	13117.2274	6	15…	15	13156.3812	−12	55…	55	13078.0563	−39
31…	30	13168.7775	−14	26…	27	13114.7251	−2	16…	16	13155.4992	10	56…	56	13074.9771	45
32…	31	13168.0731	−37	27…	28	13112.1696	3	17…	17	13154.5567	−22	57…	57	13071.8320	25
33…	32	13167.3235	43	28…	29	13109.5647	61	18…	18	13153.5659	15	58…	58	13068.6291	−19
34…	33	13166.5028	−32	29…	30	13106.8915	−20	19…	19	13152.5160	13	59…	59	13065.3650 a	−12
35…	34	13165.6366	−6	31…	32	13101.4018	20	20…	20	13151.4081	−17	60…	60	13062.0680 a	6
36…	35	13164.7133	4	32…	33	13098.5705	−7	21…	21	13150.2498	−1	64…	64	13048.2770 a	43
37…	36	13163.7328	−0	33…	34	13095.6916	33	22…	22	13149.0350	1	67…	67	13037.3460 a	56
38…	37	13162.6961	−11	34…	35	13092.7534	25	23…	23	13147.7649	2	68…	68	13033.5830 a	−13
39…	38	13161.6048	−10	36…	37	13086.7087	−45	26…	26	13143.6237	0	70…	70	13025.9110 a	75
40…	39	13160.4614	26	37…	38	13083.6168	40	27…	27	13142.1326	−6	72…	72	13017.9950 a	−25
41…	40	13159.2563	1	38…	39	13080.4584	3	28…	28	13140.5892	14	73…	73	13013.9640 a	42
42…	41	13157.9919	−58	39…	40	13077.2502	12	29…	29	13138.9874	2	75…	75	13005.7230 a	85
43…	42	13156.6855	19	40…	41	13073.9853	−4	30…	30	13137.3314	−2	77…	77	12997.2500 a	80
44…	43	13155.3148	11	41…	42	13070.6669	−11	31…	31	13135.6203	−8	78…	78	12992.9280 a	76
45…	44	13153.8927	47	42…	43	13067.3024	63	32…	32	13133.8558	3	81…	81	12979.6020 a	−10
47…	46	13150.8667	−24	43…	44	13063.8714	15	33…	33	13132.0324	−25	83…	83	12970.4400 a	−13
48…	47	13149.2740	−18	45…	46	13056.8522	−24	34…	34	13130.1606	12				
49…	48	13147.6167	−98	46…	47	13053.2743	87								
							$A\,{}^3\Phi_2$–$X\,{}^3\Delta_1$ 1–0								
19…	18	14889.1248	90	46…	45	14866.0610 a	111	26…	27	14831.3990 a	−10	21…	21	14866.7324	30
20…	19	14889.0270	−46	47…	46	14864.3370 a	−73	31…	32	14817.8170 a	−109	22…	22	14865.4753	−2
21…	20	14888.8862	−32	48…	47	14862.6030 a	271	34…	35	14808.9430 a	−356	23…	23	14864.1651	16
22…	21	14888.6816	−76	49…	48	14860.7290 a	−157	35…	36	14805.9220 a	118	24…	24	14862.7954	19
23…	22	14888.4256	−50	52…	51	14854.8610 a	−105	37…	38	14799.5880 a	−68	25…	25	14861.3610 a	−41
24…	23	14888.1047	−91	54…	53	14850.6330 a	−46	38…	39	14796.3400 a	−73	26…	26	14859.8857	73
25…	24	14887.7374	−10	56…	55	14846.1460 a	−10	40…	41	14789.6560 a	−163	27…	27	14858.3304	−28
26…	25	14887.2990	−54	58…	57	14841.4070 a	91	44…	45	14775.5900 a	−65	28…	28	14856.7310	17
27…	26	14886.8084	−32	60…	59	14836.4070 a	184	58…	59	14718.5840 a	185	29…	29	14855.0672	6
28…	27	14886.2594	−5	65…	64	14822.7060 a	−90	8….	8	14877.8004	−17	30…	30	14853.3419	−29
29…	28	14885.6487	−3	67…	66	14816.7760 a	−47	9….	9	14877.2939	12	31…	31	14851.5673	33
30…	29	14884.9795	7	68…	67	14813.7260 a	130	10…	10	14876.7318	53	32…	32	14849.7262	22
32…	31	14883.4610 a	9	71…	70	14804.1130 a	79	11…	11	14876.1069	34	33…	33	14847.8234	−10
33…	32	14882.6070 a	−41	12…	13	14861.7170 a	173	12…	12	14875.4265	29	34…	34	14845.8710 a	58
36…	35	14879.7015	−21	15…	16	14856.1660 a	131	13…	13	14874.6908	41	35…	35	14843.8420	−43
37…	36	14878.6160 a	23	18…	19	14850.0950 a	26	14…	14	14873.8995	68	36…	36	14841.7663	−12
38…	37	14877.4650 a	19	19…	20	14847.9558	−18	15…	15	14873.0455	39	37…	37	14839.6333	48
39…	38	14876.2510 a	−6	20…	21	14845.7586	−68	16…	16	14872.1338	6	38…	38	14837.4298	5
40…	39	14874.9840 a	50	21…	22	14843.5203	46	17…	17	14871.1695	20	39…	39	14835.1679	−17
43…	42	14870.7890 a	−39	22…	23	14841.2126	43	18…	18	14870.1373	−71	40…	40	14832.8441	−52
44…	43	14869.2640 a	−100	24…	25	14836.4070 a	−131	19…	19	14869.0613	−24	41…	41	14830.4705	24
45…	44	14867.7050 a	119	25…	26	14833.9430 a	39	20…	20	14867.9243	−11	42…	42	14828.0237	−23

J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$
43…	43	14825.5241	14	52…	52	14800.2130 a	49	62…	62	14766.0698	−74	72…	72	14725.4070 a	−20
44…	44	14822.9559	−21	53…	53	14797.0847	23	63…	63	14762.3087	−3	73…	73	14720.9800 a	−16
45…	45	14820.3349	32	54…	54	14793.8938	4	65…	65	14754.5700 a	−64	77…	77	14702.5940 a	17
46…	46	14817.6510 a	73	55…	55	14790.6460 a	52	66…	66	14750.6080 a	−35	78…	78	14697.8150 a	−58
47…	47	14814.8991	53	56…	56	14787.3213	−32	67…	67	14746.5800 a	−6	80…	80	14688.0760 a	43
48…	48	14812.0780 a	−37	58…	58	14780.5094	93	68…	68	14742.4770 a	−64	81…	81	14683.0890 a	−46
49…	49	14809.2128	55	59…	59	14776.9865	−49	69…	69	14738.2930 a	−267	82…	82	14678.0620 a	158
50…	50	14806.2720 a	17	60…	60	14773.4200 a	19	70…	70	14734.0810 a	−84	83…	83	14672.9550 a	257
51…	51	14803.2810 a	103												
							$A\,^3\Phi_3$–$X\,^3\Delta_2$ 1–0								
3….	2	14958.4844	−57	33…	32	14955.2592	−16	37…	38	14870.6183	−27	24…	24	14936.6667	5
4….	3	14959.3022	−29	34…	33	14954.1631	30	38…	39	14867.1459	−4	25…	25	14935.0816	6
6….	5	14960.7420	−32	35…	34	14952.9942	−5	39…	40	14863.6128	50	26…	26	14933.4266	−55
7….	6	14961.3701	−0	36…	35	14951.7738	93	41…	42	14856.3445	55	27…	27	14931.7227	33
8….	7	14961.9197	−120	37…	36	14950.4754	60	42…	43	14852.6151	66	28…	28	14929.9434	6
9….	8	14962.4152	−146	38…	37	14949.1070	−24	43…	44	14848.8062	−78	29…	29	14928.1066	41
10…	9	14962.8651	7	39…	38	14947.6879	34	44…	45	14844.9570	17	30…	30	14926.2033	51
11…	10	14963.2311	−45	40…	39	14946.1894	−50	45…	46	14841.0369	46	31…	31	14924.2310	11
12…	11	14963.5367	−66	41…	40	14944.6405	14	6….	6	14954.3265	−100	32…	32	14922.2034	58
13…	12	14963.7821	−53	15…	16	14930.9910	11	7….	7	14953.8866	−71	33…	33	14920.1043	30
14…	13	14963.9709	29	16…	17	14928.9148	41	8….	8	14953.3876	1	34…	34	14917.9410	2
18…	17	14964.0588	53	17…	18	14926.7562	−121	9….	9	14952.8178	−2	35…	35	14915.7152	−9
19…	18	14963.9146	−10	18…	19	14924.5674	47	10…	10	14952.1838	−13	36…	36	14913.4255	−17
20…	19	14963.7142	4	19…	20	14922.2919	−20	12…	12	14950.7352	57	37…	37	14911.0752	12
21…	20	14963.4528	46	20…	21	14919.9618	0	13…	13	14949.9095	29	38…	38	14908.6577	13
22…	21	14963.1205	18	21…	22	14917.5633	−32	14…	14	14949.0209	7	39…	39	14906.1743	−1
23…	22	14962.7207	−45	22…	23	14915.1099	20	15…	15	14948.0664	−42	40…	40	14903.6259	−19
24…	23	14962.2651	−26	23…	24	14912.5855	−6	16…	16	14947.0645	70	41…	41	14901.0191	24
25…	24	14961.7427	−35	25…	26	14907.3487	−38	17…	17	14945.9827	18	42…	42	14898.3415	6
26…	25	14961.1608	2	26…	27	14904.6493	86	18…	18	14944.8424	15	43…	43	14895.5996	−8
27…	26	14960.5040	−67	27…	28	14901.8693	37	19…	19	14943.6377	3	44…	44	14892.7942	−9
28…	27	14959.7965	−1	28…	29	14899.0235	−35	20…	20	14942.3676	−27	45…	45	14889.9268	19
29…	28	14959.0151	−32	29…	30	14896.1214	−36	21…	21	14941.0389	−8	46…	46	14886.9900	4
30…	29	14958.1748	−8	30…	31	14893.1682	87	22…	22	14939.6507	52	49…	49	14877.7992	60
31…	30	14957.2649	−36	31…	32	14890.1318	13	23…	23	14938.1840	−37	50…	50	14874.6040	68
32…	31	14956.3063	94	35…	36	14877.3755	−34								
							$A\,^3\Phi_4$–$X\,^3\Delta_3$ 1–0								
11…	10	15029.9645	−30	36…	35	15016.0910	20	10…	10	15018.8501	−23	30…	30	14991.0274	19
12…	11	15030.2267	−33	37…	36	15014.6430	−44	12…	12	15017.2870	−31	31…	31	14988.9236	5
13…	12	15030.4233	−11	38…	37	15013.1343	−31	13…	13	15016.4096	23	32…	32	14986.7535	6
16…	15	15030.6037	47	39…	38	15011.5599	8	14…	14	15015.4550	−15	33…	33	14984.5168	18
17…	16	15030.5181	−30	40…	39	15009.9139	14	15…	15	15014.4383	4	34…	34	14982.2136	40
18…	17	15030.3738	−11	43…	42	15004.5669	46	16…	16	15013.3479	−35	35…	35	14979.8391	26
19…	18	15030.1590	−16	44…	43	15002.6370	−51	17…	17	15012.2001	30	36…	36	14977.3954	−3
20…	19	15029.8811	29	45…	44	15000.6582	48	18…	18	15010.9718	−33	37…	37	14974.8881	8
21…	20	15029.5236	−41	46…	45	14998.5996	34	19…	19	15009.6848	−5	38…	38	14972.3169	57
22…	21	15029.1053	−37	48…	47	14994.2800	39	20…	20	15008.3283	8	41…	41	14964.1798	28
24…	23	15028.0653	−19	49…	48	14992.0128	−2	21…	21	15006.9000	−21	42…	42	14961.3277	−26
25…	24	15027.4465	24	16…	17	14995.0260	−16	22…	22	15005.4110	20	43…	43	14958.4157	−2
26…	25	15026.7508	−19	17…	18	14992.7953	−21	23…	23	15003.8434	−46	44…	44	14955.4351	14
27…	26	15025.9934	1	18…	19	14990.5078	81	24…	24	15002.2177	−17	45…	45	14952.3844	6
28…	27	15025.1646	−10	19…	20	14988.1394	48	25…	25	15000.5223	−6	47…	47	14946.0852	43
29…	28	15024.2690	−8	20…	21	14985.7042	22	26…	26	14998.7610	22	48…	48	14942.8305	27
30…	29	15023.3032	−26	21…	22	14983.2012	−10	27…	27	14996.9271	0	49…	49	14939.5022	−46
31…	30	15022.2700	−36	22…	23	14980.6360	12	28…	28	14995.0260	−16	51…	51	14932.6711	97
33…	32	15020.0007	−38	8….	8	15020.1363	−67	29…	29	14993.0631	27	52…	52	14929.1363	−4
35…	34	15017.4627	2	9….	9	15019.5256	−60								
							$A\,^3\Phi_2$–$X\,^3\Delta_1$ 1–1								
21…	20	13890.1175	28	28…	27	13888.4785	−83	35…	34	13884.2568	8	42…	41	13877.3610	−37
22…	21	13890.0348	−48	29…	28	13888.0396	−34	36…	35	13883.4333	−25	44…	43	13874.8947	−36
23…	22	13889.9031	−91	30…	29	13887.5392	−67	37…	36	13882.5633	21	45…	44	13873.5784	−29
24…	23	13889.7215	−109	31…	30	13886.9891	−64	38…	37	13881.6294	−25	46…	45	13872.2068	−12
25…	24	13889.4907	−94	32…	31	13886.3907	−6	39…	38	13880.6416	−62	47…	46	13870.7837	53
26…	25	13889.2075	−77	33…	32	13885.7326	−9	40…	39	13879.6116	29	48…	47	13869.2900	−22
27…	26	13888.8667	−107	34…	33	13885.0261	44	41…	40	13878.5130	−14	49…	48	13867.7486	−7

TABLE 1—*Continued*

J′	J″	Observed	O−C	J′	J″	Observed	O−C	J′	J″	Observed	O−C	J′	J″	Observed	O−C
50...	49	13866.1501	8	31....	32	13820.9502	−1	16...	16	13872.9195	16	52....	52	13808.4278	9
51...	50	13864.4919	−2	32....	33	13818.2566	−3	17...	17	13872.0556	22	53....	53	13805.6199	−2
52...	51	13862.7711	−64	33....	34	13815.5036	−68	18...	18	13871.1380	6	54....	54	13802.7534	−28
53...	52	13861.0083	29	34....	35	13812.7094	−13	19...	19	13870.1743	44	56....	56	13796.8480	−79
55...	54	13857.2918	45	35....	36	13809.8588	11	20...	20	13869.1492	−16	57....	57	13793.8152	−40
56...	55	13855.3392	−18	36....	37	13806.9495	−17	21...	21	13868.0791	−7	58....	58	13790.7311	65
57...	56	13853.3392	29	37....	38	13803.9886	−24	23...	23	13865.7821	0	59....	59	13787.5624	−95
58...	57	13851.2725	−4	40....	41	13794.7931	60	24...	24	13864.5555	4	60....	60	13784.3607	−0
60...	59	13846.9580 a	−111	41....	42	13791.6111	3	25...	25	13863.2787	28	61....	61	13781.0930 a	20
61...	60	13844.7250 a	−34	42....	43	13788.3723	−78	26...	26	13861.9431	−12	62....	62	13777.7632	8
62...	61	13842.4360 a	79	43....	44	13785.0962	15	27...	27	13860.5607	6	63....	63	13774.3650	−10
67...	66	13830.0440 a	181	47....	48	13771.4057	16	28...	28	13859.1253	20	64....	64	13770.9300 a	16
4....	5	13874.0677	99	48....	49	13767.8372	−60	29...	29	13857.6324	−12	65....	65	13767.4093	−13
5....	6	13872.7530	−20	50....	51	13760.5513	−31	30...	30	13856.0917	7	66....	66	13763.8451	−11
6....	7	13871.4065	49	51....	52	13756.8400 a	138	31...	31	13854.4909	−44	67....	67	13760.2210 a	−10
7....	8	13870.0042	67	52....	53	13753.0433	16	32...	32	13852.8457	−7	70....	70	13748.9990 a	46
8....	9	13868.5467	39	53....	54	13749.1932	−78	33...	33	13851.1434	−6	71....	71	13745.1260 a	−18
10...	11	13865.4839	26	55....	56	13741.3508	10	34...	34	13849.3886	5	72....	72	13741.2120 a	117
11...	12	13863.8846	103	56....	57	13737.3410	20	35...	35	13847.5799	14	74....	74	13733.1580 a	−41
12...	13	13862.2150	−15	57....	58	13733.2682	−29	36...	36	13845.7126	−24	76....	76	13724.8900 a	120
14...	15	13858.7501	19	58....	59	13729.1558	99	37...	37	13843.7978	4	78....	78	13716.3580 a	116
15...	16	13856.9393	17	67....	68	13689.4310 a	175	38...	38	13841.8243	−12	80....	80	13707.5700 a	44
17...	18	13853.1590	−38	71....	72	13670.2410 a	152	39...	39	13839.7997	3	82....	82	13698.5430 a	92
18...	19	13851.2021	36	3.....	3	13879.5096	−4	40...	40	13837.7181	−4	84....	84	13689.2600 a	107
19...	20	13849.1807	−22	4.....	4	13879.3066	−10	41...	41	13835.5852	22	87....	87	13674.8700 a	250
20...	21	13847.1160	2	5.....	5	13879.0682	134	42...	42	13833.3920	−5	88....	88	13669.9190 a	38
21...	22	13844.9886	−86	6.....	6	13878.7534	24	43...	43	13831.1435	−34	89....	89	13664.9250 a	39
22...	23	13842.8280	10	7.....	7	13878.3975	8	44...	44	13828.8464	3	91....	91	13654.7400 a	16
23...	24	13840.6039	−10	8.....	8	13877.9939	22	45...	45	13826.4908	10	92....	92	13649.5480 a	−14
24...	25	13838.3235	−74	9.....	9	13877.5358	−1	46...	46	13824.0776	−3	93....	93	13644.3170 a	220
25...	26	13836.0042	−8	10....	10	13877.0276	−16	47...	47	13821.6130	29	94....	94	13638.9590 a	−16
26...	27	13833.6286	18	11....	11	13876.4730	14	48...	48	13819.0817	−45	95....	95	13633.6000 a	108
27...	28	13831.1983	18	12....	12	13875.8577	−54	49...	49	13816.5041	−21	96....	96	13628.1510 a	137
28...	29	13828.7140	1	13....	13	13875.2024	−11	50...	50	13813.8705	8	97....	97	13622.6240 a	48
29...	30	13826.1782	−5	14....	14	13874.4960	32	51...	51	13811.1718	−49	100...	100	13605.6720 a	74
30...	31	13823.5916	7	15....	15	13873.7317	7								
							$A\,^3\Phi_3$–$X\,^3\Delta_2$ 1–1								
16...	15	13964.8285	7	52....	51	13931.2574	−33	22...	23	13916.7530	40	63....	64	13772.0290 a	36
17...	16	13964.9134	−15	53....	52	13929.2396	54	23...	24	13914.3716	−19	65....	66	13762.4460 a	10
21...	20	13964.6836	−30	54....	53	13927.1387	−86	24...	25	13911.9395	−14	66....	67	13757.5630 a	−19
22...	21	13964.4838	−14	55....	54	13925.0008	7	25...	26	13909.4521	10	68....	69	13747.6200 a	−43
23...	22	13964.2326	67	56....	55	13922.7903	−19	26...	27	13906.9068	28	71....	72	13732.2600 a	−7
24...	23	13963.9039	−48	57....	56	13920.5207	−29	27...	28	13904.3023	26	72....	73	13727.0180 a	−2
25...	24	13963.5285	−50	59....	58	13915.8070 a	31	28...	29	13901.6376	−5	73....	74	13721.7150 a	0
26...	25	13963.1031	27	62....	61	13908.2710 a	49	29...	30	13898.9209	17	76....	77	13705.4420 a	33
27...	26	13962.6054	−38	63....	62	13905.6330 a	23	30...	31	13896.1424	−5	77....	78	13699.8810 a	−97
28...	27	13962.0590	−9	65....	64	13900.1770 a	20	31...	32	13893.3055	−39	78....	79	13694.2830 a	18
29...	28	13961.4533	9	68....	67	13891.5280 a	12	32...	33	13890.4153	−30	79....	80	13688.5980 a	−12
30...	29	13960.7906	39	70....	69	13885.4490 a	−10	33...	34	13887.4697	−1	80....	81	13682.8730 a	−40
31...	30	13960.0670	43	78....	77	13858.6210 a	−32	34...	35	13884.4693	54	83....	84	13665.3140 a	83
32...	31	13959.2897	93	82....	81	13843.6830 a	13	35...	36	13881.4087	83	84....	85	13659.3240 a	1
33...	32	13958.4401	5	84....	83	13835.8220 a	−11	36...	37	13878.2816	23	86....	87	13647.1670 a	−55
34...	33	13957.5399	−4	86....	85	13827.7340 a	297	37...	38	13875.0977	−29	87....	88	13640.9990 a	−35
35...	34	13956.5790	−36	87....	86	13823.5650 a	181	38...	39	13871.8676	33	89....	90	13628.4710 a	−22
36...	35	13955.5666	5	90....	89	13810.6920 a	119	39...	40	13868.5709	7	90....	91	13622.1060 a	−75
37...	36	13954.4941	32	97....	96	13778.3460 a	152	40...	41	13865.2174	−10	6.....	6	13954.4213	−14
38...	37	13953.3542	−28	103...	102	13747.9620 a	−46	41...	42	13861.8110	22	7.....	7	13954.0260	35
39...	38	13952.1636	−5	10....	11	13940.8025	37	43...	44	13854.8193	35	8.....	8	13953.5604	−46
40...	39	13950.9118	−6	11....	12	13939.1088	1	46...	47	13843.8897	−13	9.....	9	13953.0481	−23
41...	40	13949.6132	116	12....	13	13937.3647	33	47...	48	13840.1268	−64	10....	10	13952.4770	−15
42...	41	13948.2418	101	14....	15	13933.6967	10	48...	49	13836.3194	24	11....	11	13951.8463	−31
43...	42	13946.8046	20	15....	16	13931.7715	−57	50...	51	13828.5070 a	−25	12....	12	13951.1645	15
44...	43	13945.3126	−16	16....	17	13929.8045	29	51...	52	13824.5160 a	−20	13....	13	13950.4186	−8
45...	44	13943.7694	30	17....	18	13927.7710	21	52...	53	13820.4700 a	20	14....	14	13949.6132	−53
46...	45	13942.1583	−9	18....	19	13925.6780	−11	53...	54	13816.3560 a	−33	15....	15	13948.7612	10
47...	46	13940.4872	−51	19....	20	13923.5304	−19	55...	56	13807.9720 a	65	16....	16	13947.8449	2
48...	47	13938.7647	−10	20....	21	13921.3248	−36	61...	62	13781.3700 a	32	17....	17	13946.8730	12
51...	50	13933.2200	−70	21....	22	13919.0666	−6	62...	63	13776.7260 a	1	18....	18	13945.8400	−16

TABLE 1—*Continued*

J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$
19…	19	13944.7544	5	38…	38	13913.1364	3	57…	57	13860.4424	−61	83….	83	13753.0510 a	4
20…	20	13943.6089	1	39…	39	13910.8929	5	58…	58	13857.0798	−19	87….	87	13732.7770 a	−5
21…	21	13942.4090	28	40…	40	13908.5970	68	59…	59	13853.6546	−3	88….	88	13727.5430 a	−58
22…	22	13941.1445	−18	41…	41	13906.2284	−13	60…	60	13850.1711	34	89….	89	13722.2540 a	−16
23…	23	13939.8277	−10	42…	42	13903.8130	23	61…	61	13846.6217	14	90….	90	13716.8960 a	−17
24…	24	13938.4544	8	43…	43	13901.3368	36	62…	62	13843.0089	−36	91….	91	13711.4760 a	11
25…	25	13937.0189	−20	44…	44	13898.8019	50	63…	63	13839.3401	−40	92….	92	13705.9820 a	−50
26…	26	13935.5260 a	−46	45…	45	13896.2043	25	65…	65	13831.8256	5	93….	93	13700.4330 a	−8
27…	27	13933.9813	−14	46…	46	13893.5441	−40	66…	66	13827.9646	−97	94….	94	13694.8130 a	−22
28…	28	13932.3764	−6	47…	47	13890.8345	−8	67…	67	13824.0594	−30	96….	96	13683.3750 a	−57
29…	29	13930.7139	4	48…	48	13888.0631	−5	68…	68	13820.0915	23	97….	97	13677.5650 a	5
30…	30	13928.9925	2	49…	49	13885.2318	−10	69…	69	13816.0501	−47	98….	98	13671.6850 a	29
31…	31	13927.2144	11	50…	50	13882.3388	−40	70…	70	13811.9558	−31	101…	101	13653.6320 a	−32
32…	32	13925.3789	25	51…	51	13879.3939	2	71…	71	13807.8070	57	102…	102	13647.4850 a	−7
33…	33	13923.4759	−56	52…	52	13876.3845	−6	72…	72	13803.5838	18	103…	103	13641.2680 a	−10
34…	34	13921.5308	22	53…	53	13873.3185	14	78…	78	13776.9620 a	10	104…	104	13634.9850 a	3
35…	35	13919.5155	−22	54…	54	13870.1866	−29	80…	80	13767.5850 a	−14	106…	106	13622.2210 a	81
36…	36	13917.4494	7	56…	56	13863.7541	−13	82…	82	13757.9590 a	−3	107…	107	13615.7070 a	−17
37…	37	13915.3242	27												
								$A\,^3\Phi_4$–$X\,^3\Delta_3$ 1–1							
12…	11	14030.5933	27	54…	53	13988.5229	56	43…	44	13917.3104	−28	35….	35	13983.7017	−16
13…	12	14030.8616	20	55…	54	13986.2047	269	44…	45	13913.5572	73	36….	36	13981.4893	29
14…	13	14031.0663	−4	57…	56	13981.3060	−45	45…	46	13909.7358	99	37….	37	13979.2123	43
15…	14	14031.2090	−30	58…	57	13978.7802	−25	46…	47	13905.8386	−25	38….	38	13976.8590	−93
16…	15	14031.3043	90	59…	58	13976.1889	−29	47…	48	13901.9054	97	39….	39	13974.4759	88
18…	17	14031.2801	39	61…	60	13970.8239	27	48…	49	13897.8971	77	40….	40	13972.0039	−6
19…	18	14031.1744	5	62…	61	13968.0472	59	49…	50	13893.8233	8	41….	41	13969.4775	−29
20…	19	14031.0088	−8	63…	62	13965.1887	−94	68…	69	13804.9710 a	−73	42….	42	13966.8956	6
21…	20	14030.7834	−0	16…	17	13995.9320	30	74…	75	13772.3050 a	−203	43….	43	13964.2456	−24
22…	21	14030.4974	21	17…	18	13993.8073	−34	8….	8	14020.3213	43	44….	44	13961.5397	2
26…	25	14028.7157	−77	18…	19	13991.6240	−72	9….	9	14019.7550	−66	45….	45	13958.7709	13
27…	26	14028.1338	82	19…	20	13989.3927	23	10…	10	14019.1479	34	46….	46	13955.9347	−35
28…	27	14027.4619	−39	20…	21	13987.0967	83	11…	11	14018.4666	8	47….	47	13953.0481	28
29…	28	14026.7421	−19	21…	22	13984.7222	−30	12…	12	14017.7189	−64	48….	48	13950.0911	2
30…	29	14025.9715	112	22…	23	13982.2972	−37	13…	13	14016.9211	−21	49….	49	13947.0748	1
31…	30	14025.1166	21	23…	24	13979.8103	−51	14…	14	14016.0549	−46	50….	50	13943.9929	−43
32…	31	14024.2053	−15	24…	25	13977.2627	−63	16…	16	14014.1481	10	51….	51	13940.8574	−5
33…	32	14023.2305	−67	25…	26	13974.6615	1	17…	17	14013.0923	−63	52….	52	13937.6567	−3
34…	33	14022.2064	10	26…	27	13972.0039	111	19…	19	14010.8108	−58	53….	53	13934.3953	9
35…	34	14021.1149	32	27…	28	13969.2686	54	20…	20	14009.5795	−38	54….	54	13931.0729	28
36…	35	14019.9558	−1	28…	29	13966.4734	8	21…	21	14008.2929	34	55….	55	13927.6787	−54
37…	36	14018.7350	−31	29…	30	13963.6232	20	22…	22	14006.9301	−19	56….	56	13924.2336	−25
38…	37	14017.4608	26	30…	31	13960.7101	14	23…	23	14005.5162	22	57….	57	13920.7291	27
39…	38	14016.1201	38	31…	32	13957.7363	9	24…	24	14004.0287	−59	58….	58	13917.1555	8
40…	39	14014.7043	−79	32…	33	13954.6978	−35	25…	25	14002.4950	14	59….	59	13913.5287	75
41…	40	14013.2393	−67	33…	34	13951.6011	−52	26…	26	14000.8910	−1	60….	60	13909.8226	−30
42…	41	14011.7241	65	34…	35	13948.4484	−21	27…	27	13999.2310	38	61….	61	13906.0747	68
45…	44	14006.7569	−24	35…	36	13945.2301	−37	28…	28	13997.5028	10	62….	62	13902.2494	13
46…	45	14004.9891	71	36…	37	13941.9581	18	29…	29	13995.7149	0	63….	63	13898.3641	−20
47…	46	14003.1380	−44	37…	38	13938.6187	6	30…	30	13993.8644	−21	64….	64	13894.4301	81
48…	47	14001.2393	−11	39…	40	13931.7591	−3	31…	31	13991.9564	−3	65….	65	13890.4153	−1
50…	49	13997.2482	−12	40…	41	13928.2378	−12	32…	32	13989.9864	8	66….	66	13886.3371	−93
51…	50	13995.1647	45	41…	42	13924.6517	−61	33…	33	13987.9514	−15	67….	67	13882.2071	−80
53…	52	13990.7892	−50	42…	43	13921.0180	21	34…	34	13985.8589	1	70….	70	13869.4300 a	−15
								$A\,^3\Phi_2$–$X\,^3\Delta_1$ 1–2							
12…	11	12897.9856	20	29…	28	12899.6046	−3	41…	40	12892.5693	20	54….	53	12876.9230 a	29
13…	12	12898.4427	−24	30…	29	12899.2911	90	42…	41	12891.6622	−26	55….	54	12875.3740 a	148
14…	13	12898.8643	28	31…	30	12898.9108	−10	43…	42	12890.7157	29	61….	60	12864.8990 a	58
15…	14	12899.2241	−82	32…	31	12898.4941	0	44…	43	12889.7114	3	62….	61	12862.9620 a	−15
16…	15	12899.5514	−65	33…	32	12898.0290	4	45…	44	12888.6642	46	65….	64	12856.8570 a	46
17…	16	12899.8354	−25	34…	33	12897.5139	−14	46…	45	12887.5607	27	66….	65	12854.7170 a	97
18…	17	12900.0649	−73	35…	34	12896.9506	−33	47…	46	12886.4022	−40	68….	67	12850.2720 a	181
20…	19	12900.4142	105	36…	35	12896.3387	−56	48…	47	12885.1981	−58	70….	69	12845.5800 a	−12
21…	20	12900.5070	64	37…	36	12895.6881	17	49…	48	12883.9457	−54	72….	71	12840.6860 a	−15
22…	21	12900.5499	−14	38…	37	12894.9855	56	50…	49	12882.6376	−98	81….	80	12815.8850 a	6
27…	26	12900.0998	−94	39…	38	12894.2205	−42	51…	50	12881.2888	−38	10….	11	12875.0073	28
28…	27	12899.8831	25	40…	39	12893.4166	−39	52…	51	12879.8880	14	11….	12	12873.4850 a	156

TABLE 1—*Continued*

J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$
12…	13	12871.8935	40	50…	51	12777.6550 a	−85	27…	27	12871.9540	2	56…	56	12815.5993	−13
13…	14	12870.2633	−13	51…	52	12774.2390 a	−110	28…	28	12870.6900 a	48	57…	57	12812.9024	−72
14…	15	12868.5980	32	56…	57	12756.4190 a	−104	29…	29	12869.3668	−29	58…	58	12810.1760 a	91
15…	16	12866.8940 a	140	58…	59	12748.9170 a	−294	30…	30	12868.0038	−36	59…	59	12807.3750 a	27
16…	17	12865.1227	27	62…	63	12733.3640 a	−7	31…	31	12866.5926	−54	60…	60	12804.5140 a	−11
18…	19	12861.4627	−18	67…	68	12712.6880 a	−299	32…	32	12865.1326	−88	61…	61	12801.6240 a	−23
19…	20	12859.5740 a	52	4….	4	12888.4989	31	33…	33	12863.6374	−1	62…	62	12798.6660 a	−87
21…	22	12855.6380	−29	5….	5	12888.2691	−37	34…	34	12862.0873	12	63…	63	12795.6720 a	17
22…	23	12853.6116	31	6….	6	12888.0036	−14	35…	35	12860.4865	−6	64…	64	12792.6120 a	−9
23…	24	12851.5321	17	7….	7	12887.6903	−23	36…	36	12858.8408	6	65…	65	12789.5250 a	225
24…	25	12849.4020	−45	8….	8	12887.3348	−6	37…	37	12857.1439	−14	66…	66	12786.3550 a	163
25…	26	12847.2301	−65	9….	9	12886.9314	−21	38…	38	12855.4010	−15	67…	67	12783.1210 a	−4
26…	27	12845.0315	109	10…	10	12886.4854	−12	39…	39	12853.6116	5	68…	68	12779.8570 a	66
27…	28	12842.7521	−64	11…	11	12885.9958	9	40…	40	12851.7682	−33	69…	69	12776.5200 a	−54
28…	29	12840.4535	35	12…	12	12885.4569	−13	41…	41	12849.8795	−36	70…	70	12773.1420 a	−44
29…	30	12838.0976	25	13…	13	12884.8775	11	42…	42	12847.9432	−27	71…	71	12769.7270 a	140
30…	31	12835.6946	10	14…	14	12884.2518	22	43…	43	12845.9502	−96	72…	72	12766.2390 a	139
31…	32	12833.2387	−67	15…	15	12883.5763	−13	44…	44	12843.9333	89	73…	73	12762.6870 a	45
32…	33	12830.7512	8	16…	16	12882.8593	−10	45…	45	12841.8365	−33	75…	75	12755.4590 a	268
33…	34	12828.2062	−22	17…	17	12882.0965	−12	46…	46	12839.7031	−25	76…	76	12751.7250 a	8
34…	35	12825.6287	94	18…	18	12881.2888	−8	47…	47	12837.5196	−22	78…	78	12744.1500 a	88
35…	36	12822.9751	−78	19…	19	12880.4347	−12	48…	48	12835.2899	18	79…	79	12740.2570 a	−89
36…	37	12820.3006	14	20…	20	12879.5353	−13	49…	49	12832.9990 a	−53	80…	80	12736.3310 a	−35
37…	38	12817.5681	2	21…	21	12878.5914	−2	50…	50	12830.6618	−85	81…	81	12732.3530 a	64
38…	39	12814.7900	11	22…	22	12877.6019	13	51…	51	12828.2815	−43	82…	82	12728.3150 a	128
39…	40	12811.9670 a	50	23…	23	12876.5627	−10	52…	52	12825.8521	13	84…	84	12720.0580 a	152
40…	41	12809.0833	−39	24…	24	12875.4802	−6	53…	53	12823.3634	−15	86…	86	12711.5530 a	−16
41…	42	12806.1640 a	−2	25…	25	12874.3488	−27	54…	54	12820.8251	−29	87…	87	12707.2060 a	−18
48…	49	12784.3470 a	57	26…	26	12873.1758	−1	55…	55	12818.2378	−22	88…	88	12702.8180 a	−17
							$A\,^3\Phi_3$–$X\,^3\Delta_2$ 1–2								
3….	2	12967.5986	−38	46…	45	12957.6336	8	23…	24	12925.3278	−29	69…	70	12766.9890 a	14
4….	3	12968.4515	−26	47…	46	12956.2483	−6	24…	25	12923.0481	−34	70…	71	12762.3070 a	9
5….	4	12969.2571	24	48…	47	12954.8140 a	23	25…	26	12920.7192	−20	71…	72	12757.5700 a	−4
6….	5	12970.0056	15	49…	48	12953.3210 a	1	26…	27	12918.3474	76	73…	74	12747.9420 a	63
7….	6	12970.7047	23	51…	50	12950.1780 a	−2	27…	28	12915.9055	−20	74…	75	12743.0350 a	−16
8….	7	12971.3472	−23	52…	51	12948.5320 a	59	28…	29	12913.4221	−18	75…	76	12738.0750 a	−76
9….	8	12971.9476	22	54…	53	12945.0560 a	−38	29…	30	12910.8930 a	38	76…	77	12733.0760 a	22
10…	9	12972.4935	33	57…	56	12939.4680 a	145	30…	31	12908.3014	−18	77…	78	12728.0090 a	−9
11…	10	12972.9857	21	58…	57	12937.4790 a	32	31…	32	12905.6686	25	78…	79	12722.8770 a	−14
12…	11	12973.4165	−93	59…	58	12935.4420 a	−14	32…	33	12902.9780 a	2	79…	80	12717.7170 a	3
13…	12	12973.8154	−12	60…	59	12933.3560 a	−1	33…	34	12900.2490	109	80…	81	12712.4760 a	−11
14…	13	12974.1511	−50	61…	60	12931.2140 a	0	34…	35	12897.4551	79	4….	4	12964.2244	−59
15…	14	12974.4427	−15	62…	61	12929.0120 a	−48	35…	36	12894.6084	35	5….	5	12963.9735	−16
16…	15	12974.6805	−4	64…	63	12924.4560 a	−6	36…	37	12891.7117	4	6….	6	12963.6697	8
17…	16	12974.8817	156	65…	64	12922.0900 a	−34	37…	38	12888.7628	−33	7….	7	12963.3113	−2
18…	17	12975.0028	29	66…	65	12919.6770 a	24	38…	39	12885.7685	−10	8….	8	12962.9007	−25
19…	18	12975.0912	92	67…	66	12917.2100 a	99	39…	40	12882.7191	−23	9….	9	12962.4432	−5
24…	23	12974.7161	−26	68…	67	12914.6730 a	33	40…	41	12879.6230	13	10…	10	12961.9344	14
25…	24	12974.4905	−2	69…	68	12912.0780 a	−52	41…	42	12876.4737	35	11…	11	12961.3703	−11
26…	25	12974.2144	34	71…	70	12906.7420 a	3	42…	43	12873.2735	63	12…	12	12960.7601	15
27…	26	12973.8782	−12	72…	71	12903.9860 a	−3	43…	44	12870.0072	−52	13…	13	12960.0945	−2
28…	27	12973.4852	−106	74…	73	12898.3110 a	55	44…	45	12866.7065	6	14…	14	12959.3765	−31
29…	28	12973.0546	−55	76…	75	12892.3950 a	−19	45…	46	12863.3440 a	−34	15…	15	12958.6084	−50
30…	29	12972.5690	−35	77…	76	12889.3570 a	2	47…	48	12856.4770 a	24	16…	16	12957.7964	5
31…	30	12972.0316	−11	79…	78	12883.1090 a	48	48…	49	12852.9640 a	38	17…	17	12956.9261	−12
32…	31	12971.4400	−7	84…	83	12866.4570 a	−18	50…	51	12845.7770 a	21	18…	18	12956.0084	10
33…	32	12970.7884	−80	10…	11	12950.3231	22	51…	52	12842.0950 a	−89	19…	19	12955.0329	−33
34…	33	12970.0962	−36	11…	12	12948.7003	−39	54…	55	12830.7750 a	−14	20…	20	12954.0146	8
35…	34	12969.3484	−25	12…	13	12947.0303	−64	55…	56	12826.8970 a	16	21…	21	12952.9406	5
36…	35	12968.5494	−1	13…	14	12945.3237	56	56…	57	12822.9680 a	62	22…	22	12951.8118	−33
37…	36	12967.6937	−17	14…	15	12943.5530	43	58…	59	12814.9380 a	18	23…	23	12950.6383	−3
38…	37	12966.7913	24	15…	16	12941.7299	16	59…	60	12810.8470 a	30	24…	24	12949.4131	24
39…	38	12965.8300	4	16…	17	12939.8513	−58	60…	61	12806.7040 a	52	25…	25	12948.1325	10
40…	39	12964.8186	11	17…	18	12937.9307	−41	61…	62	12802.5000 a	−4	26…	26	12946.8048	40
41…	40	12963.7546	19	18…	19	12935.9644	28	62…	63	12798.2470 a	−18	27…	27	12945.4174	−11
42…	41	12962.6319	−30	19…	20	12933.9385	11	63…	64	12793.9520 a	82	28…	28	12943.9832	−15
43…	42	12961.4742	101	20…	21	12931.8609	−13	66…	67	12780.7080 a	3	29…	29	12942.4984	−10
44…	43	12960.2390	−12	21…	22	12929.7363	3	67…	68	12776.1860 a	−23	30…	30	12940.9613	−10
45…	44	12958.9469	−162	22…	23	12927.5579	−10	68…	69	12771.6170 a	21	31…	31	12939.3715	−21

TABLE 1—*Continued*

J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$
32…	32	12937.7348	16	48…	48	12904.4046	−5	65…	65	12854.1430 a	−24	83…	83	12783.6820 a	−43
33…	33	12936.0417	7	49…	49	12901.8720	−41	66…	66	12850.7020 a	−6	84…	84	12779.2350 a	−15
34…	34	12934.2944	−26	50…	50	12899.2911	−30	67…	67	12847.2100 a	48	85…	85	12774.7260 a	−32
35…	35	12932.4988	−23	51…	51	12896.6489	−102	69…	69	12840.0560 a	106	87…	87	12765.5460 a	42
36…	36	12930.6520	−12	52…	52	12893.9737	28	70…	70	12836.3840 a	12	88…	88	12760.8480 a	−13
37…	37	12928.7537	3	53…	53	12891.2209	−87	71…	71	12832.6660 a	10	90…	90	12751.3220 a	−40
38…	38	12926.7984	−32	54…	54	12888.4305	−44	72…	72	12828.9000 a	83	91…	91	12746.4630 a	−78
39…	39	12924.7921	−54	55…	55	12885.5772	−97	73…	73	12825.0610 a	−19	92…	92	12741.5540 a	−30
40…	40	12922.7390	−24	56…	56	12882.6862	9	75…	75	12817.2390 a	10	93…	93	12736.5950 a	107
41…	41	12920.6313	−16	57…	57	12879.7301	0	76…	76	12813.2380 a	−36	94…	94	12731.5490 a	−37
42…	42	12918.4678	−44	58…	58	12876.7250 a	38	77…	77	12809.1880 a	−10	95…	95	12726.4640 a	21
43…	43	12916.2587	−4	59…	59	12873.6630 a	46	78…	78	12805.0650 a	−152	96…	96	12721.3100 a	−18
44…	44	12913.9933	−2	61…	61	12867.3730 a	20	80…	80	12796.7000 a	69	97…	97	12716.1030 a	9
45…	45	12911.6733	−21	62…	62	12864.1470 a	9	81…	81	12792.4120 a	−24	98…	98	12710.8310 a	−17
46…	46	12909.3017	−30	63…	63	12860.8670 a	0	82…	82	12788.0770 a	−19				
47…	47	12906.8850 a	37	64…	64	12857.5330 a	−4								
$A\,^3\Phi_4$–$X\,^3\Delta_3$ 1–2															
5….	4	13036.1496	12	50…	49	13014.0217	−19	38…	39	12949.2067	−14	36…	36	12994.7623	2
6….	5	13036.8790	−26	51…	50	13012.2419	−56	39…	40	12946.0006	20	37…	37	12992.7056	−96
7….	6	13037.5534	−58	52…	51	13010.4165	13	40…	41	12942.7233	−114	38…	38	12990.6122	−10
8….	7	13038.1808	−5	53…	52	13008.5359	93	41…	42	12939.4322	158	39…	39	12988.4618	58
9….	8	13038.7468	−9	55…	54	13004.5819	15	42…	43	12936.0417	−19	40…	40	12986.2452	15
10…	9	13039.2564	−23	57…	56	13000.4084	−1	43…	44	12932.6202	38	41…	41	12983.9811	49
11…	10	13039.7129	−11	58…	57	12998.2461	82	44…	45	12929.1377	30	42…	42	12981.6522	−13
12…	11	13040.1139	2	60…	59	12993.7301	35	45…	46	12925.5958	−28	43…	43	12979.2754	−3
13…	12	13040.4564	−12	61…	60	12991.3892	33	46…	47	12922.0018	−62	44…	44	12976.8366	−60
14…	13	13040.7493	32	62…	61	12988.9874	−10	47…	48	12918.3474	−156	45…	45	12974.3583	39
16…	15	13041.1572	11	63…	62	12986.5402	61	48…	49	12914.6729	92	46…	46	12971.8095	−14
17…	16	13041.2787	12	10…	11	13016.8720	−17	8….	8	13029.6473	−52	47…	47	12969.2104	−18
18…	17	13041.3456	22	11…	12	13015.1992	6	9….	9	13029.1618	85	48…	48	12966.5532	−50
21…	20	13041.2051	−18	12…	13	13013.4599	−85	10…	10	13028.5998	10	49…	49	12963.8440	−50
23…	22	13040.8393	16	13…	14	13011.6832	3	11…	11	13027.9841	−48	50…	50	12961.0755	−89
24…	23	13040.5733	38	14…	15	13009.8506	81	13…	13	13026.6058	31	51…	51	12958.2820 a	174
25…	24	13040.2458	2	15…	16	13007.9468	0	14…	14	13025.8229	−35	52…	52	12955.3944	50
26…	25	13039.8668	6	16…	17	13005.9934	−27	15…	15	13024.9915	−34	53…	53	12952.4629	41
27…	26	13039.4331	22	17…	18	13003.9925	22	16…	16	13024.1088	8	54…	54	12949.4596	−13
28…	27	13038.9433	33	18…	19	13001.9363	67	17…	17	13023.1658	1	55…	55	12946.4305	−7
29…	28	13038.3887	−46	19…	20	12999.8122	−17	18…	18	13022.1674	−6	56…	56	12943.3319	−24
30…	29	13037.7908	−1	20…	21	12997.6420	−12	19…	19	13021.1145	−6	57…	57	12940.1806	−10
31…	30	13037.1352	22	21…	22	12995.4163	−13	20…	20	13020.0059	−10	59…	59	12933.7113	15
32…	31	13036.4209	18	22…	23	12993.1334	−38	21…	21	13018.8424	−9	62…	62	12923.5854	12
33…	32	13035.6485	−11	23…	24	12990.7994	−24	22…	22	13017.6238	−7	63…	63	12920.0938	−35
34…	33	13034.8234	−9	24…	25	12988.4194	77	23…	23	13016.3508	4	64…	64	12916.5450	−96
36…	35	13033.0092	28	25…	26	12985.9661	−6	24…	24	13015.0328	118	65…	65	12912.9499	−59
37…	36	13032.0108	−30	26…	27	12983.4641	−29	25…	25	13013.6491	127	66…	66	12909.3017	7
39…	38	13029.8630	18	27…	28	12980.9049	−77	26…	26	13012.1954	−11	67…	67	12905.5802	−99
40…	39	13028.7017	6	28…	29	12978.2965	−68	27…	27	13010.7003	−11	68…	68	12901.8156	−73
41…	40	13027.4856	5	29…	30	12975.6419	24	28…	28	13009.1483	−28	76…	76	12869.6480 a	−49
42…	41	13026.2105	−28	30…	31	12972.9113	−97	29…	29	13007.5470	14	77…	77	12865.3710 a	−51
43…	42	13024.8861	6	31…	32	12970.1450	−29	30…	30	13005.8852	3	79…	79	12856.6450 a	−61
44…	43	13023.4967	−52	32…	33	12967.3250	49	31…	31	13004.1696	5	81…	81	12847.6990 a	22
45…	44	13022.0600	−23	33…	34	12964.4364	−13	32…	32	13002.3977	−2	83…	83	12838.4970 a	−15
46…	45	13020.5706	39	34…	35	12961.4742	−267	33…	33	13000.5726	9	84…	84	12833.8470 a	137
47…	46	13019.0256	106	35…	36	12958.5212	117	34…	34	12998.6895	−9	88…	88	12814.5180 a	−18
48…	47	13017.4025	−48	36…	37	12955.4645	10								
$A\,^3\Phi_2$–$X\,^3\Delta_1$ 2–1															
7….	6	14737.8903	−37	17…	16	14741.2527	2	29…	28	14737.6138	−10	39…	38	14728.0258	−78
8….	7	14738.4923	42	20…	19	14741.1326	−14	30…	29	14736.9289	11	40…	39	14726.7338	−72
9….	8	14739.0241	−9	21…	20	14740.9739	−41	31…	30	14736.1783	−26	41…	40	14725.3901	34
10…	9	14739.5050	3	22…	21	14740.7598	−38	32…	31	14735.3741	0	42…	41	14723.9712	6
11…	10	14739.9254	−16	23…	22	14740.4912	5	33…	32	14734.4999	−73	43…	42	14722.4952	25
12…	11	14740.2984	66	24…	23	14740.1584	−6	34…	33	14733.5700	−101	44…	43	14720.9571	46
13…	12	14740.6027	34	25…	24	14739.7688	4	35…	34	14732.5896	−29	45…	44	14719.3571	70
14…	13	14740.8564	72	26…	25	14739.3195	6	36…	35	14731.5558	116	46…	45	14717.6815	−35
15…	14	14741.0437	24	27…	26	14738.8198	96	37…	36	14730.4368	18	47…	46	14715.9633	61
16…	15	14741.1757	−1	28…	27	14738.2351	−71	38…	37	14729.2640	−10	48…	47	14714.1602	−62

TABLE 1—*Continued*

J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$
49…	48	14712.3111	−13	31…	32	14670.1307	−52	13…	13	14726.9550	22	40…	40	14684.8527	19
51…	50	14708.4185	44	32…	33	14667.2440	43	14…	14	14726.1517	−18	41…	41	14682.4531	−22
52…	51	14706.3642	−52	33…	34	14664.2796	−45	15…	15	14725.2959	−8	42…	42	14679.9998	12
54…	53	14702.0860 a	−17	34…	35	14661.2684	−6	16…	16	14724.3750	−74	43…	43	14677.4805	2
58…	57	14692.7450 a	−44	36…	37	14655.0586	−10	17…	17	14723.4118	15	44…	44	14674.9008	5
66…	65	14670.9340 a	96	37…	38	14651.8619	−30	18…	18	14722.3805	0	45…	45	14672.2484	−10
7….	8	14722.1510 a	57	38…	39	14648.6082	−19	19…	19	14721.2962	35	46…	46	14669.5585	37
10…	11	14717.4567	−15	39…	40	14645.2989	39	20…	20	14720.1488	18	47…	47	14666.7884	−4
11…	12	14715.7855	38	40…	41	14641.9114	−80	21…	21	14718.9450	19	48…	48	14663.9653	49
12…	13	14714.0410	−70	41…	42	14638.4863	31	22…	22	14717.6815	4	49…	49	14661.0601	−92
13…	14	14712.2616	45	42…	43	14634.9829	−31	23…	23	14716.3620	14	50…	50	14658.1136	−20
14…	15	14710.4008	−81	43…	44	14631.4259	−22	24…	24	14714.9854	37	51…	51	14655.0889	−99
16…	17	14706.5345	−58	44…	45	14627.8019	−70	25…	25	14713.5446	4	53…	53	14648.8776	21
17…	18	14704.5225	27	45…	46	14624.1348	65	26…	26	14712.0476	−4	54…	54	14645.6665	−21
18…	19	14702.4413	−2	46…	47	14620.3794	−70	27…	27	14710.4946	18	55…	55	14642.3960	−19
19…	20	14700.3072	14	47…	48	14616.5841	13	28…	28	14708.8818	31	56…	56	14639.0664	31
20…	21	14698.1171	50	48…	49	14612.7188	15	29…	29	14707.2074	20	57…	57	14635.6633	−11
21…	22	14695.8606	0	50…	51	14604.8024	22	30…	30	14705.4743	14	58…	58	14632.1935	−77
22…	23	14693.5555	45	51…	52	14600.7432	−50	31…	31	14703.6822	14	59…	59	14628.6776	41
23…	24	14691.1823	−10	52…	53	14596.6374	37	32…	32	14701.8300	8	60…	60	14625.0769	−41
24…	25	14688.7633	58	53…	54	14592.4509	−54	33…	33	14699.9209	32	61…	61	14621.4332	98
25…	26	14686.2715	−18	7….	7	14730.5368	−77	34…	34	14697.9492	28	62…	62	14617.7070	63
26…	27	14683.7293	−13	8….	8	14730.0860	−29	35…	35	14695.9161	11	63…	63	14613.9162	36
27…	28	14681.1319	26	9….	9	14729.5764	3	36…	36	14693.8244	10	64…	64	14610.0602	13
28…	29	14678.4646	−47	10…	10	14729.0055	−6	37…	37	14691.6708	−5	65…	65	14606.1328	−66
29…	30	14675.7507	2	11…	11	14728.3775	−15	38…	38	14689.4574	−12	66…	66	14602.1558	19
30…	31	14672.9719	−9	12…	12	14727.6968	22	39…	39	14687.1830	−22				
								$A\,^3\Phi_3$–$X\,^3\Delta_2$ 2–1							
6….	5	14812.6913	−17	40…	39	14797.7044	32	44…	45	14696.9272	−56	36…	36	14765.2249	19
7….	6	14813.3120	22	41…	40	14796.1319	40	45…	46	14692.9941	−90	37…	37	14762.8603	12
8….	7	14813.8685	57	43…	42	14792.7813	−35	7….	7	14805.8877	117	38…	38	14760.4238	−67
9….	8	14814.3541	19	48…	47	14783.2751	0	8….	8	14805.3658	−16	39…	39	14757.9378	6
10…	9	14814.7686	−92	49…	48	14781.1717	−32	10…	10	14804.1570	−24	40…	40	14755.3809	18
11…	10	14815.1333	−64	50…	49	14779.0105	21	11…	11	14803.4590	−11	41…	41	14752.7537	−24
12…	11	14815.4375	−3	51…	50	14776.7783	30	12…	12	14802.6921	−50	42…	42	14750.0670	−12
13…	12	14815.6776	57	53…	52	14772.1140	44	13…	13	14801.8684	−19	43…	43	14747.3181	28
14…	13	14815.8355	−68	54…	53	14769.6688	−80	14…	14	14800.9788	−11	44…	44	14744.4982	8
15…	14	14815.9521	34	16…	17	14780.9698	49	15…	15	14800.0184	−75	45…	45	14741.6130	−12
18…	17	14815.8745	−96	17…	18	14778.8238	2	16…	16	14799.0074	−7	46…	46	14738.6680	22
19…	18	14815.7355	10	18…	19	14776.6163	−26	17…	17	14797.9304	39	47…	47	14735.6539	18
20…	19	14815.5185	−23	19…	20	14774.3451	−55	18…	18	14796.7791	−22	48…	48	14732.5755	25
21…	20	14815.2474	46	20…	21	14772.0186	−2	19…	19	14795.5734	13	49…	49	14729.4222	−60
22…	21	14814.8991	−17	21…	22	14769.6243	9	20…	20	14794.3021	29	50…	50	14726.2172	−8
23…	22	14814.4891	−53	22…	23	14767.1673	28	21…	21	14792.9594	−31	51…	51	14722.9358	−62
24…	23	14814.0243	4	23…	24	14764.6357	−64	22…	22	14791.5582	−36	52…	52	14719.5963	−40
25…	24	14813.4865	−24	24…	25	14762.0574	13	23…	23	14790.0948	−24	53…	53	14716.1952	26
26…	25	14812.8882	−13	26…	27	14756.6956	26	24…	24	14788.5692	5	54…	54	14712.7216	26
27…	26	14812.2276	19	27…	28	14753.9143	−19	25…	25	14786.9804	42	55…	55	14709.1758	−34
28…	27	14811.4954	−19	31…	32	14742.1716	4	26…	26	14785.3184	−13	56…	56	14705.5796	64
29…	28	14810.6988	−56	32…	33	14739.0733	−22	27…	27	14783.6028	37	57…	57	14701.8999	−10
30…	29	14809.8464	−5	33…	34	14735.9237	78	28…	28	14781.8203	59	58…	58	14698.1701	79
31…	30	14808.9262	17	34…	35	14732.6885	−40	29…	29	14779.9671	16	59…	59	14694.3571	1
32…	31	14807.9395	20	36…	37	14726.0594	58	30…	30	14778.0525	1	61…	61	14686.5371	−93
33…	32	14806.8950	93	38…	39	14719.1512	−75	31…	31	14776.0772	20	62…	62	14682.5438	30
34…	33	14805.7688	−1	39…	40	14715.6221	71	32…	32	14774.0322	−13	63…	63	14678.4646	−36
35…	34	14804.5853	−18	40…	41	14712.0078	6	33…	33	14771.9266	−10	64…	64	14674.3430	146
36…	35	14803.3403	−1	41…	42	14708.3328	−23	34…	34	14769.7642	70	65…	65	14670.1307	92
37…	36	14802.0270	−14	43…	44	14700.8063	83	35…	35	14767.5251	27	66…	66	14665.8405	−65
38…	37	14800.6499	−15												
								$A\,^3\Phi_4$–$X\,^3\Delta_3$ 2–1							
8….	7	14880.4234	−13	18…	17	14881.9322	−16	25…	24	14878.9262	37	36…	35	14867.4144	−23
9….	8	14880.8869	38	19…	18	14881.7056	−31	26…	25	14878.2172	−15	15…	16	14848.9668	−59
10…	9	14881.2666	−66	20…	19	14881.4197	44	27…	26	14877.4534	69	16…	17	14846.7993	−13
11…	10	14881.5872	−77	21…	20	14881.0515	−20	28…	27	14876.6059	−0	18…	19	14842.2893	7
12…	11	14881.8442	−42	22…	21	14880.6182	−52	33…	32	14871.3799	37	19…	20	14839.9139	−11
13…	12	14882.0333	−1	23…	22	14880.1245	−3	34…	33	14870.1346	97	20…	21	14837.4952	12
17…	16	14882.0939	35	24…	23	14879.5557	−21	35…	34	14868.8063	13	22…	23	14832.4342	52

TABLE 1—*Continued*

J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$
23…	24	14829.7955	5	44…	45	14758.9145	−24	24…	24	14853.8535	−57	41…	41	14815.6776	−35
24…	25	14827.0944	8	46…	47	14750.6188	−10	25…	25	14852.1625	56	42…	42	14812.8222	−20
25…	26	14824.3256	10	47…	48	14746.3757	52	26…	26	14850.3864	−1	43…	43	14809.9017	24
26…	27	14821.4876	−5	10…	10	14870.5482	−26	27…	27	14848.5465	−17	44…	44	14806.8950	−11
27…	28	14818.5803	−39	11…	11	14869.7873	−137	28…	28	14846.6426	6	45…	45	14803.8445	−12
29…	30	14812.5716	−24	12…	12	14868.9851	20	29…	29	14844.6682	5	46…	46	14800.7129	−40
30…	31	14809.4685	6	13…	13	14868.0956	−16	30…	30	14842.6233	−24	47…	47	14797.5159	−42
32…	33	14803.0562	27	14…	14	14867.1434	4	31…	31	14840.5132	−24	48…	48	14794.2551	−2
33…	34	14799.7503	50	15…	15	14866.1228	20	32…	32	14838.3443	65	49…	49	14790.9267	43
36…	37	14789.4197	26	16…	16	14865.0313	7	33…	33	14836.0976	56	50…	50	14787.5252	37
37…	38	14785.8390	−8	17…	17	14863.8710	−13	34…	34	14833.7755	−28	52…	52	14780.5094	−58
38…	39	14782.1947	−6	18…	18	14862.6483	24	35…	35	14831.3968	1	53…	53	14776.9119	21
39…	40	14778.4797	−39	19…	19	14861.3608	94	36…	36	14828.9519	47	54…	54	14773.2328	−33
40…	41	14774.7012	−34	20…	20	14859.9931	41	37…	37	14826.4319	22	55…	55	14769.4895	−48
41…	42	14770.8643	58	21…	21	14858.5638	52	38…	38	14823.8475	30	56…	56	14765.6814	−27
42…	43	14766.9504	52	22…	22	14857.0623	22	39…	39	14821.1854	−59	57…	57	14761.7999	−56
43…	44	14762.9602	−44	23…	23	14855.4903	−34	40…	40	14818.4760	59	58…	58	14757.8626	40
$A\,^3\Phi_2$–$X\,^3\Delta_1$ 2–2															
16…	16	13734.3260 a	12	25…	25	13724.6160 a	−38	37…	37	13705.0300 a	107	51…	51	13672.2050 a	−28
17…	17	13733.4660 a	114	27…	27	13721.8870 a	4	39…	39	13700.9990 a	20	59…	59	13648.4800 a	61
18…	18	13732.5340 a	14	29…	29	13718.9460 a	45	41…	41	13696.7530 a	−24	62…	62	13638.6100 a	−29
19…	19	13731.5740 a	153	32…	32	13714.1130 a	−112	42…	42	13694.5530 a	11	63…	63	13635.1910 a	−16
23…	23	13727.1470 a	48	33…	33	13712.3950 a	−162	43…	43	13692.2910 a	−20	64…	64	13631.7470 a	35
24…	24	13725.9040 a	−33	36…	36	13706.9430 a	−56	46…	46	13685.1850 a	24				
$A\,^3\Phi_3$–$X\,^3\Delta_2$ 2–2															
35…	34	13817.3550 a	−5	58…	59	13656.0050 a	−118	43…	43	13762.2440 a	27	65…	65	13692.4410 a	−7
40…	39	13811.6100 a	36	62…	63	13637.7770 a	−1	46…	46	13754.4330 a	105	68…	68	13680.6620 a	31
41…	40	13810.2570 a	−221	63…	64	13633.0720 a	41	47…	47	13751.6930 a	−51	69…	69	13676.6170 a	85
53…	52	13789.7010 a	55	22…	22	13802.2400 a	94	50…	50	13743.1690 a	−2	70…	70	13672.4940 a	−24
61…	60	13771.1730 a	330	25…	25	13798.0970 a	102	51…	51	13740.2120 a	46	74…	74	13655.4290 a	−1
26…	27	13768.1310 a	21	26…	26	13796.5820 a	−78	53…	53	13734.1170 a	119	75…	75	13651.0150 a	82
27…	28	13765.5180 a	−59	30…	30	13790.0190 a	−34	54…	54	13730.9620 a	−23	77…	77	13641.9640 a	−10
41…	42	13723.0170 a	204	35…	35	13780.5060 a	3	56…	56	13724.5050 a	19	78…	78	13637.3540 a	−10
46…	47	13705.0300 a	−248	37…	37	13776.2940 a	30	57…	57	13721.1880 a	55	80…	80	13627.9560 a	10
47…	48	13701.2960 a	46	39…	39	13771.8420 a	−4	59…	59	13714.3590 a	−16	81…	81	13623.1710 a	155
49…	50	13693.5720 a	−171	40…	40	13769.5330 a	28	61…	61	13707.2970 a	−1	82…	82	13618.2850 a	−76
55…	56	13669.0640 a	−83	41…	41	13767.1580 a	−13	63…	63	13699.9990 a	79				
$A\,^3\Phi_2$–$X\,^3\Delta_1$ 2–3															
6….	5	12764.8620	44	48…	47	12755.2230 a	161	39…	40	12682.6071	−1	33…	33	12734.1005	−17
7….	6	12765.5750	−57	49…	48	12753.9500 a	152	40…	41	12679.7363	89	34…	34	12732.5472	61
9….	8	12766.8942	25	53…	52	12748.3290 a	−50	43…	44	12670.8070 a	101	36…	36	12729.2708	−42
10…	9	12767.4743	−50	57…	56	12741.8910 a	−130	44…	45	12667.7200 a	−27	37…	37	12727.5682	−15
12…	11	12768.5188	0	12…	13	12742.5736	−15	45…	46	12664.6080 a	86	38…	38	12725.8143	−17
13…	12	12768.9664	−38	13…	14	12740.9550 a	27	11…	11	12756.6041	−18	39…	39	12724.0153	15
14…	13	12769.3724	−38	14…	15	12739.2767	−76	12…	12	12756.0592	−63	40…	40	12722.1654	24
16…	15	12770.0488	−24	15…	16	12737.5681	−29	13…	13	12755.4778	−20	41…	41	12720.2635	3
17…	16	12770.3265	64	16…	17	12735.8111	−11	14…	14	12754.8488	0	42…	42	12718.3157	12
18…	17	12770.5422	−8	17…	18	12734.0102	22	15…	15	12754.1740	19	43…	43	12716.3177	11
19…	18	12770.7138	−60	20…	21	12728.3247	30	16…	16	12753.4536	36	44…	44	12714.2666	−26
20…	19	12770.8512	6	21…	22	12726.3349	1	17…	17	12752.6822	−1	45…	45	12712.1682	−42
21…	20	12770.9330	−21	22…	23	12724.2985	−34	18…	18	12751.8695	8	46…	46	12710.0284	26
22…	21	12770.9663	−70	23…	24	12722.2175	−55	19…	19	12751.0067	−27	47…	47	12707.8297	4
25…	24	12770.8048	−33	24…	25	12720.1017	37	20…	20	12750.1046	6	49…	49	12703.2850	−10
26…	25	12770.6596	2	25…	26	12717.9283	15	21…	21	12749.1567	40	50…	50	12700.9373	−13
27…	26	12770.4673	35	26…	27	12715.7110	17	22…	22	12748.1533	−19	51…	51	12698.5444	36
28…	27	12770.2196	−13	27…	28	12713.4515	63	23…	23	12747.1106	−8	52…	52	12696.0933	12
29…	28	12769.9266	−41	28…	29	12711.1420 a	74	24…	24	12746.0203	−11	53…	53	12693.5885	−40
30…	29	12769.5896	−34	29…	30	12708.7756	−18	25…	25	12744.8864	17	54…	54	12691.0372	−45
31…	30	12769.2038	−40	30…	31	12706.3685	−47	26…	26	12743.6973	−42	55…	55	12688.4370 a	−25
32…	31	12768.7734	−13	31…	32	12703.9245	22	27…	27	12742.4773	57	57…	57	12683.0890 a	86
34…	33	12767.7579	−66	32…	33	12701.4215	−26	28…	28	12741.1918	−28	58…	58	12680.3270 a	40
35…	34	12767.1857	−13	33…	34	12698.8785	−2	29…	29	12739.8701	−7	59…	59	12677.5220 a	84
36…	35	12766.5579	−32	34…	35	12696.2864	4	30…	30	12738.4933	−64	60…	60	12674.6460 a	−58
37…	36	12765.8851	−16	35…	36	12693.6476	18	31…	31	12737.0811	−2	61…	61	12671.7290 a	−85
42…	41	12761.7760 a	−26	37…	38	12688.2243	20	32…	32	12735.6154	−1	65…	65	12659.5530 a	12
44…	43	12759.7990 a	101												

TABLE 1—*Continued*

J′	J″	Observed	O−C	J′	J″	Observed	O−C	J′	J″	Observed	O−C	J′	J″	Observed	O−C
							$A\,^3\Phi_3$–$X\,^2\Delta_3$ 2–3								
4….	3	12838.7582	29	50…	49	12821.5200 a	−31	52…	53	12708.7690 a	247	36…	36	12800.8345	−35
5….	4	12839.5495	9	56…	55	12811.0170 a	−24	54…	55	12701.1350 a	44	37…	37	12798.9316	13
6….	5	12840.2928	21	58…	57	12807.0920 a	95	57…	58	12689.3150 a	8	38…	38	12796.9645	−58
8….	7	12841.6209	4	62…	61	12798.5430 a	−64	60…	61	12677.0130 a	−75	39…	39	12794.9510	−70
9….	8	12842.1951	−132	63…	62	12796.2860 a	79	61…	62	12672.8150 a	−12	40…	40	12792.8909	−25
10…	9	12842.7521	74	64…	63	12793.9520 a	6	63…	64	12664.2400 a	−71	41…	41	12790.7742	−21
11…	10	12843.2264	−32	65…	64	12791.5740 a	50	5….	5	12834.3014	15	42…	42	12788.5988	−79
12…	11	12843.6680	51	66…	65	12789.1230 a	−78	6….	6	12833.9957	33	43…	43	12786.3803	−42
13…	12	12844.0405	−43	67…	66	12786.6370 a	2	7….	7	12833.6326	−10	44…	44	12784.1130 a	34
14…	13	12844.3718	−32	69…	68	12781.4820 a	15	8….	8	12833.2237	3	45…	45	12781.7850 a	30
15…	14	12844.6484	−53	71…	70	12776.0960 a	−30	9….	9	12832.7614	−6	46…	46	12779.4030 a	13
16…	15	12844.8787	−21	72…	71	12773.3380 a	145	11…	11	12831.6821	−31	47…	47	12776.9730 a	46
17…	16	12845.0539	−22	76…	75	12761.6520 a	−2	12…	12	12831.0732	34	48…	48	12774.4840 a	18
19…	18	12845.2547	29	79…	78	12752.2940 a	−30	13…	13	12830.4043	12	49…	49	12771.9420 a	−9
22…	21	12845.1654	88	81…	80	12745.7710 a	−2	14…	14	12829.6855	5	50…	50	12769.3590 a	85
25…	24	12844.5937	−5	83…	82	12739.0170 a	43	15…	15	12828.9112	−43	51…	51	12766.7050 a	1
26…	25	12844.3033	6	11…	12	12819.1041	120	16…	16	12828.0948	2	53…	53	12761.2540 a	3
28…	27	12843.5609	−23	13…	14	12815.7157	27	17…	17	12827.2260	37	55…	55	12755.5900 a	14
29…	28	12843.1101	−51	15…	16	12812.1325	32	18…	18	12826.3004	19	57…	57	12749.7100 a	13
30…	29	12842.6167	19	18…	19	12806.3710	10	19…	19	12825.3200	−32	58…	58	12746.6880 a	0
31…	30	12842.0627	5	19…	20	12804.3537	59	20…	20	12824.2959	−6	59…	59	12743.6220 a	87
32…	31	12841.4611	39	21…	22	12800.1517	16	21…	21	12823.2131	−52	60…	60	12740.4850 a	5
33…	32	12840.7945	−52	22…	23	12797.9721	−23	22…	22	12822.0874	−10	61…	61	12737.3020 a	5
34…	33	12840.0913	17	23…	24	12795.7527	53	23…	23	12820.9084	14	64…	64	12727.4300 a	39
35…	34	12839.3260	−9	25…	26	12791.1370 a	−28	24…	24	12819.6696	−44	65…	65	12724.0230 a	−21
36…	35	12838.5106	−10	26…	27	12788.7564	−26	25…	25	12818.3871	−23	66…	66	12720.5700 a	6
40…	39	12834.7121	−100	27…	28	12786.3302	32	26…	26	12817.0469	−62	67…	67	12717.0560 a	−28
41…	40	12833.6326	−97	28…	29	12783.8367	−68	27…	27	12815.6635	−15	68…	68	12713.4850 a	−81
42…	41	12832.5087	−7	30…	31	12778.7261	34	28…	28	12814.2181	−71	69…	69	12709.8670 a	−53
43…	42	12831.3230 a	−3	31…	32	12776.0792	−59	29…	29	12812.7304	−32	70…	70	12706.1990 a	29
44…	43	12830.0820 a	−18	36…	37	12762.1410 a	161	30…	30	12811.1947	46	71…	71	12702.4650 a	4
45…	44	12828.7843	−68	39…	40	12753.1420 a	126	31…	31	12809.5931	−17	72…	72	12698.6800 a	25
46…	45	12827.4380	−68	41…	42	12746.8600 a	−136	32…	32	12807.9522	47	73…	73	12694.8380 a	32
47…	46	12826.0375	−74	45…	46	12733.7580 a	191	33…	33	12806.2408	−74	75…	75	12686.9810 a	−7
48…	47	12824.5900	−14	48…	49	12723.3570 a	160	34…	34	12804.5050	81	76…	76	12682.9710 a	−0
49…	48	12823.0824	−17	51…	52	12712.4760 a	38	35…	35	12802.6924	−12				
							$A\,^3\Phi_4$–$X\,^3\Delta_3$ 2–3								
9….	8	12908.7481	98	34…	33	12904.5676	8	20…	21	12867.7951	−4	32…	32	12872.3652	−3
10…	9	12909.2499	86	35…	34	12903.6789	54	36…	37	12825.6450 a	40	33…	33	12870.5335	−3
11…	10	12909.6946	61	36…	35	12902.7168	−77	46…	47	12792.1550 a	−243	34…	34	12868.6480	12
12…	11	12910.0852	54	37…	36	12901.7197	3	12…	12	12897.3663	12	35…	35	12866.7065	21
13…	12	12910.4198	42	39…	38	12899.5493	80	13…	13	12896.6489	67	36…	36	12864.7132	65
14…	13	12910.7002	48	40…	39	12898.3715	34	14…	14	12895.8587	−51	37…	37	12862.6552	16
15…	14	12910.9147	−47	42…	41	12895.8587	48	15…	15	12895.0295	−3	38…	38	12860.5479	26
16…	15	12911.0894	18	43…	42	12894.5194	68	16…	16	12894.1369	−33	39…	39	12858.3749	−67
17…	16	12911.2018	18	44…	43	12893.1159	6	17…	17	12893.1966	14	40…	40	12856.1617	−9
18…	17	12911.2575	9	45…	44	12891.6622	4	18…	18	12892.1907	−39	41…	41	12853.8840	−42
19…	18	12911.2575	1	47…	46	12888.5864	0	19…	19	12891.1384	−2	42…	42	12851.5546	−39
20…	19	12911.2018	−5	48…	47	12886.9714	70	20…	20	12890.0307	37	43…	43	12849.1705	−30
21…	20	12911.0894	−21	49…	48	12885.2886	25	21…	21	12888.8615	15	44…	44	12846.7274	−57
22…	21	12910.9147	−101	51…	50	12881.7628	23	22…	22	12887.6350	−26	45…	45	12844.2432	59
23…	22	12910.7002	−20	6….	7	12893.1159	−6	23…	23	12886.3578	−18	46…	46	12841.6836	−26
24…	23	12910.4198	−40	7….	8	12891.6622	−54	24…	24	12885.0257	−6	47…	47	12839.0798	3
25…	24	12910.0852	−43	9….	10	12888.5995	−40	25…	25	12883.6404	28	49…	49	12833.7017	16
26…	25	12909.6946	−48	10…	11	12886.9779	−104	26…	26	12882.1950	17	50…	50	12830.9303	30
27…	26	12909.2499	−36	11…	12	12885.3094	−84	27…	27	12880.6954	16	51…	51	12828.0948	−41
28…	27	12908.7505	−11	13…	14	12881.8133	27	28…	28	12879.1364	−25	52…	52	12825.2105	−45
29…	28	12908.1922	−16	17…	18	12874.1413	82	29…	29	12877.5300	14	53…	53	12822.2753	−2
30…	29	12907.5724	−79	18…	19	12872.0717	−40	30…	30	12875.8626	−3	54…	54	12819.2797	−8
32…	31	12906.1757	−96	19…	20	12869.9657	26	31…	31	12874.1413	−6	63…	63	12789.8350 a	177
33…	32	12905.3993	−46												

TABLE 1—*Continued*

J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$
							$A\,^3\Phi_2$–$X\,^3\Delta_1$ 3–2								
8….	7	14592.0244	−50	43…	42	14575.4936	−52	45…	46	14477.6379	−31	30…	30	14558.9048	−19
9….	8	14592.5561	−9	44…	43	14573.9408	35	4….	4	14585.1779	98	31…	31	14557.1046	10
10…	9	14593.0310	41	45…	44	14572.3092	−40	5….	5	14584.8830	14	32…	32	14555.2395	−12
11…	10	14593.4394	2	13…	14	14565.9099	0	6….	6	14584.5375	−3	33…	33	14553.3154	−22
12…	11	14593.7959	22	14…	15	14564.0609	−17	7….	7	14584.1268	−98	34…	34	14551.3316	−26
13…	12	14594.0968	64	15…	16	14562.1543	−32	8….	8	14583.6792	12	35…	35	14549.2911	6
14…	13	14594.3308	16	17…	18	14558.1728	−11	9….	9	14583.1638	19	36…	36	14547.1870	8
15…	14	14594.5144	46	18…	19	14556.0976	24	10…	10	14582.5856	−28	37…	37	14545.0188	−24
16…	15	14594.6331	6	20…	21	14551.7658	23	11…	11	14581.9612	40	38…	38	14542.7895	−57
17…	16	14594.6993	24	21…	22	14549.5030	−74	12…	12	14581.2635	−48	39…	39	14540.5058	−24
22…	21	14594.1423	6	22…	23	14547.1987	−2	13…	13	14580.5194	−23	40…	40	14538.1546	−53
23…	22	14593.8524	−19	23…	24	14544.8193	−97	14…	14	14579.7154	−19	41…	41	14535.7478	−24
25…	24	14593.1055	31	25…	26	14539.9199	66	15…	15	14578.8591	40	42…	42	14533.2776	−12
26…	25	14592.6364	−10	26…	27	14537.3626	−47	16…	16	14577.9348	−1	43…	43	14530.7480	23
27…	26	14592.1096	−35	31…	32	14523.7454	−57	17…	17	14576.9554	−12	44…	44	14528.1518	12
28…	27	14591.5328	38	32…	33	14520.8517	21	18…	18	14575.9186	−16	45…	45	14525.4885	−49
29…	28	14590.8807	−45	33…	34	14517.8938	53	19…	19	14574.8281	25	46…	46	14522.7714	−24
30…	29	14590.1814	−0	34…	35	14514.8734	60	20…	20	14573.6736	10	47…	47	14519.9955	38
31…	30	14589.4158	−17	35…	36	14511.7863	−1	21…	21	14572.4649	38	48…	48	14517.1422	−48
34…	33	14586.7595	−40	36…	37	14508.6420	−32	22…	22	14571.1917	7	51…	51	14508.2303	−40
35…	34	14585.7595	22	37…	38	14505.4367	−70	23…	23	14569.8626	4	52…	52	14505.1396	28
36…	35	14584.6895	−9	38…	39	14502.1786	−30	24…	24	14568.4751	4	53…	53	14501.9745	−11
37…	36	14583.5654	32	39…	40	14498.8597	6	25…	25	14567.0298	16	54…	54	14498.7534	30
38…	37	14582.3796	69	40…	41	14495.4711	−46	26…	26	14565.5196	−30	55…	55	14495.4710	98
39…	38	14581.1249	32	41…	42	14492.0329	16	27…	27	14563.9579	1	56…	56	14492.1126	47
40…	39	14579.8119	29	42…	43	14488.5244	−14	28…	28	14562.3326	−11	57…	57	14488.6975	75
41…	40	14578.4389	45	43…	44	14484.9638	48	29…	29	14560.6480	−21				
42…	41	14576.9893	−84	44…	45	14481.3292	−16								
							$A\,^3\Phi_3$–$X\,^3\Delta_2$ 3–2								
18…	17	14669.0295	7	22…	23	14620.5381	6	10…	10	14657.4470	−5	31…	31	14629.2371	−10
19…	18	14668.8649	−28	23…	24	14618.0201	54	11…	11	14656.7438	−12	32…	32	14627.1856	−19
20…	19	14668.6469	48	24…	25	14615.4313	53	13…	13	14655.1513	32	33…	33	14625.0769	47
21…	20	14668.3566	44	25…	26	14612.7703	−71	14…	14	14654.2547	9	34…	34	14622.8877	−44
22…	21	14667.9971	−6	26…	27	14610.0616	−13	15…	15	14653.2988	33	35…	35	14620.6463	−11
23…	22	14667.5856	69	27…	28	14607.2837	−8	16…	16	14652.2752	21	36…	36	14618.3325	−53
24…	23	14667.0966	14	28…	29	14604.4408	−12	17…	17	14651.1879	11	37…	37	14615.9638	5
25…	24	14666.5533	64	29…	30	14601.5358	2	18…	18	14650.0305	−58	38…	38	14613.5162	−77
26…	25	14665.9353	13	30…	31	14598.5672	20	19…	19	14648.8233	14	39…	39	14611.0208	12
29…	28	14663.6988	−79	31…	32	14595.5294	−13	20…	20	14647.5445	12	40…	40	14608.4487	−15
31…	30	14661.9027	55	32…	33	14592.4367	46	21…	21	14646.1997	−9	41…	41	14605.8141	−15
33…	32	14659.8221	−55	33…	34	14589.2675	−18	22…	22	14644.7933	−4	42…	42	14603.1176	19
12…	13	14642.2520	−46	34…	35	14586.0390	−34	23…	23	14643.3269	43	43…	43	14600.3482	−24
15…	16	14636.4088	−17	35…	36	14582.7514	2	24…	24	14641.7877	5	44…	44	14597.5293	91
16…	17	14634.3297	−46	36…	37	14579.3930	−28	25…	25	14640.1885	9	45…	45	14594.6331	88
17…	18	14632.1971	28	37…	38	14575.9769	8	26…	26	14638.5175	−63	46…	46	14591.6667	38
18…	19	14629.9924	19	39…	40	14568.9469	35	27…	27	14636.7940	−15	48…	48	14585.5464	34
19…	20	14627.7270	40	40…	41	14565.3243	−61	28…	28	14634.9979	−50	49…	49	14582.3796	−48
20…	21	14625.3880	−37	41…	42	14561.6584	55	29…	29	14633.1450	−8	50…	50	14579.1515	−84
21…	22	14623.0013	48	42…	43	14557.9058	−50	30…	30	14631.2237	−6				
							$A\,^3\Phi_4$–$X\,^3\Delta_3$ 3–2								
21…	21	14711.4877	−203	35…	35	14684.2693	52	51…	51	14636.7605	−99	27…	26	14730.1991	19
22…	22	14709.9827	−224	36…	36	14681.8099	29	52…	52	14633.2199	−18	28…	27	14729.3510	64
23…	23	14708.4185	−154	37…	37	14679.2830	12	53…	53	14629.6008	−38	29…	28	14728.4284	50
24…	24	14706.7816	−131	38…	38	14676.6898	13	55…	55	14622.1630	−20	30…	29	14727.4467	133
25…	25	14705.0846	−26	40…	40	14671.2960	−14	56…	56	14618.3325	−98	31…	30	14726.3809	61
26…	26	14703.3076	−39	41…	41	14668.5047	50	57…	57	14614.4480	−30	34…	33	14722.7949	80
27…	27	14701.4633	−44	42…	42	14665.6350	12	58…	58	14610.4778	−132	35…	34	14721.4590	55
28…	28	14699.5642	85	43…	43	14662.6995	−3	59…	59	14606.4552	−71	36…	35	14720.0556	43
29…	29	14697.5662	−94	44…	44	14659.7001	26	22…	21	14733.4127	−181	37…	36	14718.5794	−10
30…	30	14695.5400	127	46…	46	14653.4959	76	23…	22	14732.9065	−148	38…	37	14717.0478	71
31…	31	14693.4185	76	47…	47	14650.2856	43	24…	23	14732.3384	−48	40…	39	14713.7645	96
32…	32	14691.2311	47	48…	48	14647.0042	−19	25…	24	14731.6933	−32	42…	41	14710.1953	16
33…	33	14688.9820	83	49…	49	14643.6661	36	26…	25	14730.9790	−22				
34…	34	14686.6594	65	50…	50	14640.2398	−108								

TABLE 1—*Continued*

J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$
$A\,^3\Phi_2$–$X\,^3\Delta_1$ 3–4															
8....	8	12629.9283	21	22...	22	12620.0595	−11	36...	36	12601.0605	−10	19...	18	12642.5336	48
9....	9	12629.5193	6	23...	23	12619.0097	−3	37...	37	12599.3477	18	20...	19	12642.6480	6
10...	10	12629.0653	−4	24...	24	12617.9124	−4	38...	38	12597.5873	55	21...	20	12642.7300	103
11...	11	12628.5681	8	25...	25	12616.7719	31	40...	40	12593.9176	106	23...	22	12642.7300	60
12...	12	12628.0174	−59	26...	26	12615.5779	−1	41...	41	12591.9989	29	24...	23	12642.6480	−77
13...	13	12627.4332	−5	27...	27	12614.3354	−48	42...	42	12590.0376	17	25...	24	12642.5336	−70
14...	14	12626.7935	−49	28...	28	12613.0535	−17	43...	43	12588.0226	−37	26...	25	12642.3725	−56
15...	15	12626.1178	5	29...	29	12611.7237	8	12...	11	12640.4024	−15	27...	26	12642.1621	−64
16...	16	12625.3900	−2	30...	30	12610.3441	9	13...	12	12640.8489	35	28...	27	12641.9024	−90
17...	17	12624.6206	32	31...	31	12608.9187	28	14...	13	12641.2378	−33	29...	28	12641.6000	−67
18...	18	12623.7880	−104	32...	32	12607.4442	32	15...	14	12641.6000	92	30...	29	12641.2431	−11
19...	19	12622.9357	23	33...	33	12605.9285	102	16...	15	12641.9024	78	31...	30	12640.8489	−50
20...	20	12622.0202	−19	34...	34	12604.3537	61	17...	16	12642.1621	99	32...	31	12640.4024	−32
21...	21	12621.0685	39	35...	35	12602.7290	3	18...	17	12642.3725	89				
$A\,^3\Phi_3$–$X\,^3\Delta_2$ 3–4															
7....	7	12705.3244	59	25...	25	12690.0051	−37	50...	50	12640.7776	51	25...	24	12716.0586	0
8....	8	12704.8964	−102	27...	27	12687.2758	29	51...	51	12638.1232	64	26...	25	12715.7566	14
9....	9	12704.4475	44	28...	28	12685.8262	−9	52...	52	12635.3985	−92	27...	26	12715.4002	8
10...	10	12703.9245	−37	29...	29	12684.3251	−41	11...	10	12714.8383	4	28...	27	12715.0041	127
11...	11	12703.3660	43	32...	32	12670.5236	4	12...	11	12715.2616	−8	29...	28	12714.5227	−81
12...	12	12702.7414	−22	34...	34	12676.0579	−5	13...	12	12715.6302	−49	30...	29	12714.0104	−74
13...	13	12702.0731	−9	35...	35	12674.2482	6	14...	13	12715.9571	10	31...	30	12713.4522	−1
14...	14	12701.3524	−3	36...	36	12672.3817	−28	15...	14	12716.2293	41	32...	31	12712.8334	−7
16...	16	12699.7528	−27	37...	37	12670.4734	44	16...	15	12716.4447	22	33...	32	12712.1676	43
17...	17	12698.8785	−9	38...	38	12668.4948	−64	17...	16	12716.6130	50	34...	33	12711.4424	26
18...	18	12697.9523	7	39...	39	12666.4745	−62	18...	17	12716.7219	5	35...	34	12710.6677	43
19...	19	12696.9736	14	40...	40	12664.4055	−22	19...	18	12716.7862	32	36...	35	12709.8335	−7
20...	20	12695.9371	−39	41...	41	12662.2786	−35	20...	19	12716.7862	−63	37...	36	12708.9549	28
21...	21	12694.8528	−53	43...	43	12657.8797	69	21...	20	12716.7392	−108	38...	37	12708.0143	−27
22...	22	12693.7306	71	47...	47	12648.4176	−21	22...	21	12716.6563	10	39...	38	12707.0267	−21
23...	23	12692.5392	21	48...	48	12645.9228	−12	23...	22	12716.5103	17	40...	39	12705.9896	21
24...	24	12691.3085	96	49...	49	12643.3630	−118	24...	23	12716.3160	63				
$A\,^3\Phi_4$–$X\,^3\Delta_3$ 3–4															
21...	21	12760.1969	−193	26...	26	12753.5306	−58	30...	30	12747.1955	20	35...	35	12738.0196	30
22...	22	12758.9789	−124	27...	27	12752.0420	80	31...	31	12745.4782	92	36...	36	12736.0167	18
23...	23	12757.7038	−71	28...	28	12750.4806	47	32...	32	12743.6973	82	37...	37	12733.9542	−35
24...	24	12756.3730	−19	29...	29	12748.8603	−22	34...	34	12739.9631	2	38...	38	12731.8440	−11
$A\,^3\Phi_2$–$X\,^3\Delta_1$ 4–3															
18...	17	14449.3907	16	16...	17	14415.1073	26	11...	11	14436.7914	5	34...	34	14405.9759	7
19...	18	14449.3349	112	18...	19	14411.0031	−13	12...	12	14436.1042	66	35...	35	14403.9211	21
21...	20	14449.0035	−124	19...	20	14408.8583	−84	13...	13	14435.3403	−58	36...	36	14401.8024	4
23...	22	14448.4632	−84	20...	21	14406.6604	−100	14...	14	14434.5430	65	37...	37	14399.6176	−63
24...	23	14448.1118	14	21...	22	14404.4170	14	15...	15	14433.6549	−138	38...	38	14397.3830	−16
25...	24	14447.6946	50	22...	23	14402.1006	−14	16...	16	14432.7408	−17	39...	39	14395.0806	−32
26...	25	14447.2072	−19	23...	24	14399.7322	25	17...	17	14431.7694	115	40...	40	14392.7281	65
27...	26	14446.6693	4	24...	25	14397.3013	28	18...	18	14430.7167	18	41...	41	14390.2968	−8
28...	27	14446.0698	12	25...	26	14394.8054	−29	19...	19	14429.6111	−21	43...	43	14385.2617	−20
29...	28	14445.4045	−37	26...	27	14392.2532	−58	20...	20	14428.4523	−5	44...	44	14382.6571	36
30...	29	14444.6872	−3	27...	28	14389.6472	−31	22...	22	14425.9595	41	45...	45	14379.9829	20
32...	31	14443.0605	−41	28...	29	14386.9916	92	23...	23	14424.6188	5	46...	46	14377.2504	48
33...	32	14442.1664	43	29...	30	14384.2571	23	24...	24	14423.2215	−4	47...	47	14374.4449	−26
34...	33	14441.1899	−87	30...	31	14381.4738	61	25...	25	14421.7662	−0	48...	48	14371.5947	83
35...	34	14440.1680	−60	32...	33	14375.7110	−31	26...	26	14420.2508	−4	49...	49	14368.6604	−17
36...	35	14439.0886	4	34...	35	14369.7268	66	27...	27	14418.6767	1	50...	50	14365.6716	−29
37...	36	14437.9430	21	35...	36	14366.6306	−22	28...	28	14417.0488	65	51...	51	14362.6239	6
38...	37	14436.7292	−26	36...	37	14363.4862	12	29...	29	14415.3426	−56	52...	52	14359.5045	−39
11...	12	14424.3390	13	37...	38	14360.2771	6	30...	30	14413.5914	−27	53...	53	14356.3214	−81
13...	14	14420.8248	62	8....	8	14438.5228	−3	31...	31	14411.7801	2	54...	54	14353.0890	24
14...	15	14418.9699	−22	9....	9	14438.0061	25	32...	32	14409.9044	−11	57...	57	14342.9726	18
15...	16	14417.0614	−61	10...	10	14437.4301	39	33...	33	14407.9699	−7	59...	59	14335.8878	−14

TABLE 1—*Continued*

J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$	J'	J''	Observed	$O-C$
							$A\,^3\Phi_3$–$X\,^3\Delta_2$ 4–3								
18…	17	14523.4374	−53	15…	16	14491.0507	13	10…	10	14512.0076	7	34…	34	14477.2948	30
20…	19	14523.0302	−19	16…	17	14488.9639	−107	13…	13	14509.6957	−12	35…	35	14475.0340	−28
21…	20	14522.7357	60	17…	18	14486.8350	−8	14…	14	14508.7925	−58	36…	36	14472.7190	25
22…	21	14522.3654	28	18…	19	14484.6292	−37	15…	15	14507.8364	8	37…	37	14470.3346	33
23…	22	14521.9279	−27	19…	20	14482.3681	22	16…	16	14506.8122	37	38…	38	14467.8819	12
24…	23	14521.4330	−7	20…	21	14480.0334	−14	17…	17	14505.7183	12	39…	39	14465.3650	1
26…	25	14520.2451	−1	21…	22	14477.6392	−4	19…	19	14503.3384	−28	40…	40	14462.7840	4
27…	26	14519.5455	−78	22…	23	14475.1767	−36	20…	20	14502.0546	−21	41…	41	14460.1409	38
28…	27	14518.7908	−56	23…	24	14472.6558	−11	21…	21	14500.7007	−71	42…	42	14457.4286	37
30…	29	14517.0950	79	24…	25	14470.0742	49	22…	22	14499.2972	28	43…	43	14454.6479	7
31…	30	14516.1269	−76	25…	26	14467.4114	−61	23…	23	14497.8114	−50	45…	45	14448.9001	53
32…	31	14515.1209	43	28…	29	14459.0786	18	24…	24	14496.2731	−10	46…	46	14445.9212	13
33…	32	14514.0304	−29	29…	30	14456.1614	−66	25…	25	14494.6621	−50	47…	47	14442.8894	102
35…	34	14511.6741	40	30…	31	14453.1997	48	26…	26	14492.9981	26	48…	48	14439.7700	−23
37…	36	14509.0557	112	31…	32	14450.1568	−6	27…	27	14491.2596	4	49…	49	14436.6038	43
38…	37	14507.6267	−63	32…	33	14447.0500	−56	28…	28	14489.4538	−46	50…	50	14433.3646	40
39…	38	14506.1523	−34	36…	37	14434.0013	−22	29…	29	14487.5915	−12	51…	51	14430.0532	−21
40…	39	14504.6129	5	37…	38	14430.5870	79	30…	30	14485.6703	80	53…	53	14423.2436	−20
12…	13	14496.8971	77	39…	40	14423.5353	−9	31…	31	14483.6688	17	54…	54	14419.7531	122
13…	14	14495.0064	−4	8….	8	14513.2237	−21	32…	32	14481.6067	−2	55…	55	14416.1718	22
14…	15	14493.0617	16	9….	9	14512.6465	−19	33…	33	14479.4826	7	56…	56	14412.5365	49
							$A\,^3\Phi_4$–$X\,^3\Delta_3$ 4–3								
18…	17	14588.9770	94	23…	24	14537.3054	−16	16…	16	14572.3092	28	35…	35	14538.4491	79
19…	18	14588.7204	−8	25…	26	14531.8442	54	17…	17	14571.1359	−44	36…	36	14535.9726	−20
20…	19	14588.4087	27	26…	27	14528.9958	−70	18…	18	14569.9044	−11	38…	38	14530.8359	−3
21…	20	14588.0206	−13	30…	31	14516.9819	26	19…	19	14568.6053	31	40…	40	14525.4320	78
22…	21	14587.5683	−7	34…	35	14503.8696	−6	20…	20	14567.2409	103	41…	41	14522.6187	31
23…	22	14587.0468	−4	35…	36	14500.4355	121	21…	21	14565.7913	9	43…	43	14516.7907	−23
24…	23	14586.4612	47	36…	37	14496.8993	−96	22…	22	14564.2850	33	44…	44	14513.7784	−7
26…	25	14585.0699	15	38…	39	14489.6691	−75	23…	23	14562.7049	4	45…	45	14510.6972	6
27…	26	14584.2712	2	39…	40	14485.9651	62	24…	24	14561.0606	16	46…	46	14507.5470	13
28…	27	14583.3997	−51	40…	41	14482.1721	−13	25…	25	14559.3400	−49	48…	48	14501.0426	44
29…	28	14582.4658	−38	42…	43	14474.3979	−15	26…	26	14557.5613	−10	49…	49	14497.6841	26
30…	29	14581.4661	7	43…	44	14470.4095	−13	27…	27	14555.7126	12	50…	50	14494.2546	−18
31…	30	14580.3902	−21	44…	45	14466.3534	−11	28…	28	14553.8004	84	51…	51	14490.7600	−26
32…	31	14579.2553	50	9….	9	14578.5549	48	29…	29	14551.7952	−90	52…	52	14487.1936	−65
34…	33	14576.7621	28	11…	11	14577.1049	−42	30…	30	14549.7491	11	53…	53	14483.5760	72
36…	35	14573.9951	28	12…	12	14576.2873	16	31…	31	14547.6201	−34	54…	54	14479.8619	−70
38…	37	14570.9457	−35	13…	13	14575.3992	55	32…	32	14545.4275	−30	55…	55	14476.0963	−38
39…	38	14569.3223	−18	14…	14	14574.4326	−5	33…	33	14543.1708	16	56…	56	14472.2629	3

NOTE—" a " marks lines from sunspot measurements, and $O-C$ are observed minus calculated line positions in units of 10^{-4} cm^{-1}.

two spectra, although the TiO in the sunspot is much hotter (∼3000 K). A number of additional high J rotational lines were identified in the solar spectrum as compared to the laboratory spectrum, using predictions based on the spectroscopic constants derived from the laboratory data. Rotational lines with J values up to 110 could be identified in the sunspot spectrum. The sunspot TiO measurements were shifted to the same wavenumber scale as the laboratory data. The more extensive, but lower quality, sunspot lines were then combined with the laboratory data in order to obtain improved molecular constants.

Three fits were obtained using the combined data. In the first fit the three subbands were fitted separately using a simple empirical energy-level expression

$$F(J) = T_v + B_v J(J+1) - D_v[J(J+1)]^2 + H_v[J(J+1)]^3 + L_v[J(J+1)]^4 ,$$

in order to extract separate effective rotational constants for the different vibrational levels of the individual spin components. In these fits the weak and blended rotational lines were weighted on the basis of the signal-to-noise ratio and on the extent of blending. The solar measurements were given slightly lower weights ranging from 0.005 to 0.015 cm^{-1}. In this fit the line positions of Barnes et al. (1996) and pure rotational transition frequencies of Steimle et al. (1990) and Namiki et al. (1998) were also included. The lines of Barnes et al. (1996) were adjusted to our wavenumber scale by subtraction of 0.0037 cm^{-1}. In this fit the ground-state spin-orbit intervals between the $^3\Delta_1$, $^3\Delta_2$, and $^3\Delta_3$ spin components was constrained to the values obtained by Amiot et al. (1995) by using their published term values. Our spectra do not contain any satellite branches so that we are unable to determine the spin-orbit splittings. The wavenumbers of the observed transitions are provided in Table 1. For those lines which are common to both laboratory and sunspot spectra, only the laboratory measurements are provided. The constants obtained from the individual subband fits are presented in Table 2. The combination of low-temperature hollow cathode data and high-temperature solar data has resulted in improved molecule constants.

TABLE 2

ROTATIONAL CONSTANTS (in cm^{-1}) FOR THE $X\ ^3\Delta$ AND $A\ ^3\Phi$ STATES OF TiO FROM THE EMPIRICAL SUBBAND FITS

State	Constants[a]	$v = 0$	$v = 1$	$v = 2$	$v = 3$	$v = 4$
$X\ ^3\Delta_1$	T_v	0.0	1000.019711(682)	1990.89483(103)	2972.58842(135)	3945.08008(185)
....	B_v	0.5279770748(998)	0.52502156(120)	0.52202105(181)	0.51901372(299)	0.51600085(430)
....	$D_v \times 10^7$	4.00004(508)	4.20042(660)	4.22487(892)	4.3083(196)	4.5649(218)
....	$H_v \times 10^{12}$	−9.5802(988)	−6.2559(805)	−6.718(106)	−6.368(383)	0.0
....	$L_v \times 10^{16}$	2.3518(444)	0.0	0.0	0.0	0.0
$X\ ^3\Delta_2$	T_v	96.7496[b]	1096.795480(576)	2087.674452(781)	3069.38549(101)	4041.87509(165)
....	B_v	0.5340955136(212)	0.531036358(955)	0.52797821(122)	0.52487297(120)	0.52179205(331)
....	$D_v \times 10^7$	6.367616(956)	6.32215(438)	6.37261(501)	6.29540(333)	6.3976(137)
....	$H_v \times 10^{12}$	2.5331(601)	1.1655(331)	1.3128(387)	0.0	0.0
....	$L_v \times 10^{16}$	−0.7361(451)	0.0	0.0	0.0	0.0
$X\ ^3\Delta_3$	T_v	198.2874[b]	1198.342850(839)	2189.24037(106)	3170.94224(156)	4143.4654(146)
....	B_v	0.5393848802(453)	0.53625091(188)	0.53309953(174)	0.52996797(282)	0.5267376(306)
....	$D_v \times 10^7$	7.82109(221)	7.5809(118)	7.42413(738)	7.4872(110)	7.166(152)
....	$H_v \times 10^{12}$	10.024(232)	2.758(157)	0.0	0.0	0.0
....	$L_v \times 10^{16}$	−6.127(295)	0.0	0.0	0.0	0.0
$A\ ^3\Phi_2$	T_v	14019.735576(419)	14879.841678(725)	15732.161995(915)	16576.63844(125)	17413.19012(158)
....	B_v	0.502859866(891)	0.49970779(128)	0.49656009(138)	0.49337809(201)	0.49018514(263)
....	$D_v \times 10^7$	6.47534(599)	6.47413(695)	6.58915(471)	6.60226(703)	6.64759(896)
....	$H_v \times 10^{12}$	−1.2301(757)	−1.4681(865)	0.0	0.0	0.0
$A\ ^3\Phi_3$	T_v	14192.610867(386)	15052.411844(587)	15904.451431(917)	16748.63388(137)	17584.91593(138)
....	B_v	0.505651715(740)	0.502472345(988)	0.49925965(145)	0.49606166(262)	0.49281901(205)
....	$D_v \times 10^7$	6.96823(352)	6.97267(466)	6.90463(613)	6.9625(107)	6.95814(657)
....	$H_v \times 10^{12}$	0.6838(753)	0.4217(336)	−0.5386(590)	0.0	0.0
....	$L_v \times 10^{16}$	−0.1884(485)	0.0	0.0	0.0	0.0
$A\ ^3\Phi_4$	T_v	14361.352316(632)	15220.885899(833)	16072.64304(148)	16916.49171(323)	17752.57196(201)
....	B_v	0.50862867(156)	0.50537854(151)	0.50216217(372)	0.49899320(420)	0.49568241(347)
....	$D_v \times 10^7$	7.4172(103)	7.13597(758)	7.1983(260)	7.4725(125)	7.4094(128)
....	$H_v \times 10^{12}$	2.868(315)	−3.7115(702)	−3.352(505)	0.0	0.0
....	$L_v \times 10^{16}$	−3.621(327)	0.0	0.0	0.0	0.0

[a] Numbers in parentheses are uncertainties quoted to 1 standard deviation.
[b] Extrapolated from the term values of Amiot et al. 1995.

TABLE 3

MATRIX ELEMENTS FOR $^3\Pi$ STATE

Ω'	Ω	$\langle \Omega' \| H \| \Omega \rangle$[a]
2......	2	$T + A + \frac{2}{3}\lambda + (B + A_D + \frac{2}{3}\lambda_D - \gamma_D)(X - 2)$ $+ (D + A_H + \frac{2}{3}\lambda_H - 2\gamma_H \mp q_H)(X^2 - 2X) + H(X^3 - 4X)$
2......	1	$-\{B + \frac{1}{2}A_D - \frac{1}{3}\lambda_D - \frac{1}{2}\gamma - \gamma_D)$ $+ [2D + A_H - \frac{2}{3}\lambda_H - \frac{1}{2}\gamma_D - \frac{10}{3}\gamma_H \mp \frac{1}{2}(q_D + p_H) \pm \frac{1}{3}q_H]X$ $+ (H - \frac{1}{6}\gamma_H \mp \frac{1}{3}q_H)(3X^2 + 4X)\}\sqrt{2(X-2)}$
2......	0	$\{2D - \gamma_D + \frac{4}{3}\lambda_H - \frac{8}{3}\gamma_H \pm \frac{1}{3}(q_D + 2p_H - q_H) \mp \frac{1}{2}(q + p_D + 2o_H)$ $+ [2H - \frac{2}{3}\gamma_H \mp \frac{1}{6}(q_D + 2p_H + 2q_H)](3X + 2)\}\sqrt{X(X-2)}$
1......	1	$T - \frac{4}{3}\lambda - 2\gamma + 6\gamma_D - 64\gamma_H \pm (q + 2p_D + 64q_H) \mp 6(q_D + 4p_H)$ $+ [B - \frac{4}{3}\lambda_D - 4\gamma_D + 32\gamma_H \mp \frac{1}{2}(q + 2p_D + 64q_H) \pm 3(q_D + 4p_H)](X + 2)$ $+ [D - \frac{4}{3}\lambda_H - 6\gamma_H \mp \frac{1}{2}(q_D + 4p_H) \pm 5q_H](X^2 + 8X)$ $+ (H \mp \frac{1}{2}q_H)(X^3 + 18X^2 + 16X)$
1......	0	$-\{B - \frac{1}{2}A_D - \frac{1}{3}\lambda_D - \frac{1}{2}\gamma - 2\gamma_D + 4\gamma_H \mp \frac{1}{2}(p + 2q + o_D + 16q_H) \pm (\frac{3}{2}q_D + 2p_H)$ $+ [2D - A_H - \frac{2}{3}\lambda_H - \frac{1}{2}\gamma_D - \frac{16}{3}\gamma_H \mp \frac{1}{2}(p_D + q_D + 2o_H + \frac{5}{3}p_H) \pm \frac{16}{3}q_H](X + 2)$ $+ [H - \frac{1}{6}\gamma_H \mp \frac{1}{6}(p_H + 2q_H)](3X^2 + 16X + 8)\}\sqrt{2X}$
0......	0	$T - A + \frac{2}{3}\lambda - 2\gamma + 2\gamma_D - 8\gamma_H \mp (o + p + q + 8p_H + 12q_H) \pm 2p_D$ $+ [B - A_D + \frac{2}{3}\lambda_D - 3\gamma_D + 8\gamma_H \mp (o_D + p_D) \pm 8(p_H + q_H)](X + 2)$ $+ [D - A_H + \frac{2}{3}\lambda_H - 4\gamma_H \mp (o_H + 2p_H + q_H)](X^2 + 6X + 4)$ $+ H(X^3 + 12X^2 + 24X + 8)$

[a] $X = J(J + 1)$; upper(lower) sign − e(f) parity.

TABLE 4

MATRIX ELEMENTS FOR $^3\Delta$ STATE

Ω'	Ω	$\langle\Omega'\|H\|\Omega\rangle$[a]
3	3	$T + 2A + \frac{2}{3}\lambda + \gamma + 2\gamma_D + 4\gamma_H$ $+ (B + 2A_D + \frac{2}{3}\lambda_D + 2\gamma_H)(X - 4)$ $+ (D + 2A_H + \frac{2}{3}\lambda_H - \gamma_H)(X^2 - 6X + 4)$ $+ H(X^3 - 6X^2 + 8)$
3	2	$-\{B + A_D - \frac{1}{3}\lambda_D - \frac{1}{2}(\gamma + \gamma_D) + \gamma_H$ $+ (2D + 2A_H - \frac{2}{3}\lambda_H - \frac{1}{2}\gamma_D - \frac{7}{3}\gamma_H)(X - 1)$ $+ (H - \frac{1}{6}\gamma_H)(3X^2 - 2X - 4)\}\sqrt{2(X - 6)}$
3	1	$\{2D - \gamma_D + \frac{4}{3}\lambda_H - \frac{8}{3}\gamma_H$ $+ (2H - \frac{2}{3}\gamma_H)(3X + 2)\}\sqrt{(X - 2)(X - 6)}$
2	2	$T - \frac{4}{3}\lambda - 2\gamma + 12\gamma_D - 136\gamma_H$ $+ (B - \frac{4}{3}\lambda_D - 4\gamma_D + 44\gamma_H)(X + 2)$ $+ (D - \frac{4}{3}\lambda_H - 6\gamma_H)(X^2 + 8X - 12)$ $+ H(X^3 + 18X^2 - 20X - 24)$
2	1	$-\{B - A_D - \frac{1}{3}\lambda_D - \frac{1}{2}\gamma - \frac{5}{2}\gamma_D + 9\gamma_H$ $+ (2D - 2A_H - \frac{2}{3}\lambda_H - \frac{1}{2}\gamma_D - \frac{19}{3}\gamma_H)(X + 3)$ $+ (H - \frac{1}{6}\gamma_H)(3X^2 + 22X + 12)\}\sqrt{2(X - 2)}$
1	1	$T - 2A + \frac{2}{3}\lambda - 3\gamma + 6\gamma_D - 36\gamma_H$ $+ (B - 2A_D + \frac{2}{3}\lambda_D - 4\gamma_D + 18\gamma_H)(X + 4)$ $+ (D - 2A_H + \frac{2}{3}\lambda_H - 5\gamma_H)(X^2 + 10X + 12)$ $+ H(X^3 + 18X^2 + 56X + 24)$

[a] $X = J(J + 1)$.

In the second fit the lines of the three subbands of the $A\,^3\Phi$–$X\,^3\Delta$ transition were combined and fitted simultaneously using a Hund's case (*a*) Hamiltonian for the $^3\Phi$ and $^3\Delta$ states. In this fit, we added the 1–0 band lines of the $B\,^3\Pi$–$X\,^3\Delta$ transition with an assumed precision of ± 0.002 cm^{-1}. The main difference between this present fit and the fit of Amiot et al. (1995) is that we used an N^2 Hamiltonian (Brown et al. 1979), while Amiot et al. (1995) have used an R^2 Hamiltonian. The matrix elements for the $^3\Pi$, $^3\Delta$, and $^3\Phi$ states of the N^2 Hamiltonian are provided in Tables 3, 4,

TABLE 5

MATRIX ELEMENTS FOR $^3\Phi$ STATE

Ω'	Ω	$\langle\Omega'\|H\|\Omega\rangle$[a]
4	4	$T + 3A + \frac{2}{3}\lambda + 2\gamma + 6\gamma_D + 24\gamma_H$ $+ (B + 3A_D + \frac{2}{3}\lambda_D + \gamma_D + 8\gamma_H)(X - 6)$ $+ (D + 3A_H + \frac{2}{3}\lambda_H)(X^2 - 10X + 12)$ $+ H(X^3 - 12X^2 + 16X + 24)$
4	3	$-\{B + \frac{3}{2}A_D - \frac{1}{3}\lambda_D - \frac{1}{2}\gamma + 4\gamma_H$ $+ (2D + 3A_H - \frac{2}{3}\lambda_H - \frac{1}{2}\gamma_D - \frac{4}{3}\gamma_H)(X - 2)$ $+ (H - \frac{1}{6}\gamma_H)(3X^2 - 8X - 8)\}\sqrt{2(X - 12)}$
4	2	$\{2D - \gamma_D + \frac{4}{3}\lambda_H - \frac{8}{3}\gamma_H$ $+ (2H - \frac{2}{3}\gamma_H)(3X + 2)\}\sqrt{(X - 6)(X - 12)}$
3	3	$T - \frac{4}{3}\lambda - 2\gamma + 22\gamma_D - 256\gamma_H$ $+ (B - \frac{4}{3}\lambda_D - 4\gamma_D + 64\gamma_H)(X + 2)$ $+ (D - \frac{4}{3}\lambda_H - 6\gamma_H)(X^2 + 8X - 32)$ $+ H(X^3 + 18X^2 - 80X - 64)$
3	2	$-\{B - \frac{3}{2}A_D - \frac{1}{3}\lambda_D - \frac{1}{2}\gamma - 3\gamma_D + 16\gamma_H$ $+ (2D + 3A_H - \frac{2}{3}\lambda_H - \frac{1}{2}\gamma_D - \frac{22}{3}\gamma_H)(X + 4)$ $+ (H - \frac{1}{6}\gamma_H)(3X^2 + 28X + 16)\}\sqrt{2(X - 6)}$
2	2	$T - 3A + \frac{2}{3}\lambda - 4\gamma + 12\gamma_D - 96\gamma_H$ $+ (B - 3A_D + \frac{2}{3}\lambda_D - 5\gamma_D + 32\gamma_H)(X + 6)$ $+ (D - 3A_H + \frac{2}{3}\lambda_H - 6\gamma_H)(X^2 + 14X + 24)$ $+ H(X^3 + 24X^2 + 100X + 48)$

[a] $X = J(J + 1)$.

TABLE 6

CASE A CONSTANTS IN WAVENUMBERS FOR THE $X\,^3\Delta$, $A\,^3\Phi$, AND $B\,^3\Pi$ STATES OF TiO[a]

Parameter	$v=0$	$v=1$	$v=2$	$v=3$	$v=4$
			$X\,^3\Delta$ State		
T_v	0.0	1000.040659(287)	1990.924019(386)	2972.627602(555)	3945.12686(127)
B_v	0.5338211558(159)	0.530778558(356)	0.527717794(423)	0.524637898(681)	0.52154179(204)
$D_v \times 10^7$	6.039325(698)	6.07150(112)	6.10638(117)	6.14010(176)	6.19430(793)
$H_v \times 10^{14}$	2.806(983)	0.0	0.0	0.0	0.0
A_v	50.6511629(604)	50.651278(154)	50.649515(216)	50.646525(294)	50.643099(731)
$A_{Dv} \times 10^5$	−2.646614(470)	−2.74078(810)	−2.8372(126)	−2.9835(206)	−3.4510(632)
λ_v	1.7472698(684)	1.741659(258)	1.737445(341)	1.732147(423)	1.730519(582)
$\lambda_{Dv} \times 10^6$	0.6801(144)	1.306(161)	1.669(224)	3.471(272)	0.0
			$A\,^3\Phi$ State		
T_v	14092.905684(193)	14952.717705(306)	15804.759299(485)	16648.943316(780)	17485.239326(768)
B_v	0.505716075(244)	0.502535549(416)	0.499341114(744)	0.49613864(106)	0.49290307(113)
$D_v \times 10^7$	6.937508(942)	6.94586(140)	6.96497(304)	6.99498(330)	7.01526(350)
$H_v \times 10^{14}$	8.25(102)	2.803(756)	6.01(335)	0.0	0.0
A_v	57.9573454(742)	57.853900(104)	57.753471(151)	57.648809(263)	57.558472(242)
$A_{Dv} \times 10^5$	−4.18140(290)	−4.15539(574)	−4.13958(918)	−3.8818(159)	−4.0852(172)
λ_v	−0.515184(168)	−0.512816(234)	0.510816(352)	−0.517394(361)	−0.510315(396)
$\lambda_{Dv} \times 10^6$	−4.2199(692)	−3.674(129)	−3.093(197)	0.0	0.0
			$B\,^3\Pi$ State		
T_v	...	17012.463041(147)	...	...	...
B_v	...	0.502865409(228)	...	...	...
$D_v \times 10^7$	...	6.90626(113)	...	...	...
$H_v \times 10^{14}$	...	9.82(142)	...	...	...
A_v	...	20.788469(223)	...	...	...
$A_{Dv} \times 10^4$	...	−1.1437(257)	...	...	...
$A_{Hv} \times 10^9$	...	−6.446(105)	...	...	...
$\gamma_v \times 10^2$	...	2.49139(521)	...	...	...
λ_v	...	−0.930695(235)	...	...	...
$\lambda_{Dv} \times 10^6$	...	−3.826(658)	...	...	...
$\lambda_{Hv} \times 10^{10}$	...	−5.19(161)	...	...	...
o_v	...	−0.618623(260)	...	...	...
$o_{Dv} \times 10^6$	...	1.918(427)	...	...	...
$o_{Hv} \times 10^{10}$	...	3.90(119)	...	...	...
$p_v \times 10^2$	...	2.611711(933)	...	...	...
$p_{Dv} \times 10^7$	...	1.1524(329)	...	...	...
$q_v \times 10^4$	...	2.95986(352)	...	...	...
$q_{Dv} \times 10^{10}$	...	−6.171(951)	...	...	...

[a] Standard deviation of fit, 1.0090 (unweighted rms deviation, 0.0050 cm^{-1}) involving 6120 data points and 88 adjustable parameters. Numbers in parentheses are uncertainties quoted to 1 standard deviation.

and 5, respectively. The case (*a*) constants for the $X\,^3\Delta$ ground and $A\,^3\Phi$ and $B\,^3\Pi$ excited states obtained from this fit are provided in Table 6.

In the third fit the same set of lines as used in the second fit were again fitted to determine directly the equilibrium constants for the $A\,^3\Phi$ and $X\,^3\Delta$ states. In this fit case the lines were fitted using the following polynomial,

$$f(v) = P_0 + P_1(v + \tfrac{1}{2})^1 + P_2(v + \tfrac{1}{2})^2 + P_3(v + \tfrac{1}{2})^3 + \cdots$$

to represent the vibrational dependence of all of the case (*a*) spectroscopic constants. Here $f(v)$ represents a molecular constant, and coefficients P_0, P_1, P_2, etc., are the corresponding equilibrium constants. A set of equilibrium constants obtained for the $X\,^3\Delta$ and $A\,^3\Phi$ states is provided in Table 7. The B_e equilibrium rotational constants for the $X\,^3\Delta$ and $A\,^3\Phi$ states obtained from this fit are 0.535335360(164) cm^{-1} and 0.507300491(369) cm^{-1}, respectively. These constants are in excellent agreement with those obtained from a fit using the B_v values of Table 6 and the usual expression,

$$B_v = B_e - \alpha_e(v + \tfrac{1}{2}) + \gamma_e(v + \tfrac{1}{2})^2 + \cdots .$$

The same is true for the other equilibrium constants.

The equilibrium rotational constants provide bond lengths of 1.62033709(25) Å and 1.66450728(61) Å for the $X\,^3\Delta$ and $A\,^3\Phi$ states. The equilibrium constants have been used in a RKR program to calculate the classical turning points of the potential energy curves of the $A\,^3\Phi$ and $X\,^3\Delta$ states (Table 8). The output from the RKR calculations has been used to calculate the Franck-Condon factors for the $A\,^3\Phi$–$X\,^3\Delta$ transition of TiO (Table 9). The intensity of the observed bands is consistent with the calculated Franck-Condon factors.

Although the $A\,^3\Phi$–$X\,^3\Delta$ transition of TiO has been studied previously by several workers, the constants obtained in the present work are expected to be both more accurate and more extensive. The inclusion of high J lines of the main and satellite branches in the $B\,^3\Pi$–$X\,^3\Delta$ transition results in a precise determination of the ground-state molec-

TABLE 7

EQUILIBRIUM CONSTANTS IN WAVENUMBERS FOR THE $X\ ^3\Delta$ AND $A\ ^3\Phi$ STATES OF TiO[a,b]

P_v	p_0	p_1	p_2	p_3
		$X\ ^3\Delta$ State		
T_v	0.0	1009.176435(654)	−4.561736(301)	$-3.7816(420) \times 10^{-3}$
B_v	0.535335360(164)	$-3.023758(366) \times 10^{-3}$	$-9.2120(912) \times 10^{-6}$	0.0
D_v	$6.023307(870) \times 10^{-7}$	$3.4150(632) \times 10^{-9}$	$3.20(180) \times 10^{-11}$	0.0
H_v	$6.88(161) \times 10^{-14}$	0.0	0.0	0.0
A_v	50.650414(100)	$1.934(166) \times 10^{-3}$	$-8.757(350) \times 10^{-4}$	0.0
A_{Dv}	$-2.59131(267) \times 10^{-5}$	$-1.1019(524) \times 10^{-6}$	0.0	0.0
λ_v	1.749911(138)	$-5.420(258) \times 10^{-3}$	$2.999(568) \times 10^{-4}$	0.0
λ_{Dv}	$6.724(158) \times 10^{-7}$	0.0	0.0	0.0
		$A\ ^3\Phi$ State		
T_v	14163.554562(548)	867.516894(914)	−3.833447(453)	$-1.17113(623) \times 10^{-2}$
B_v	0.507300491(369)	$-3.166620(701) \times 10^{-3}$	$-5.754(322) \times 10^{-6}$	$-3.440(406) \times 10^{-7}$
D_v	$6.93158(107) \times 10^{-7}$	$1.0894(805) \times 10^{-9}$	$1.742(265) \times 10^{-10}$	0.0
H_v	$1.143(168) \times 10^{-13}$	0.0	0.0	0.0
A_v	58.0100584(943)	−0.1058600(935)	$1.2013(169) \times 10^{-3}$	0.0
A_{Dv}	$-4.20100(328) \times 10^{-5}$	$2.598(324) \times 10^{-7}$	0.0	0.0
λ_v	−0.516346(226)	$3.052(234) \times 10^{-3}$	$-2.467(441) \times 10^{-4}$	0.0
λ_{Dv}	$-4.4856(813) \times 10^{-6}$	$1.934(546) \times 10^{-7}$	0.0	0.0

[a] $P_v = \sum_{k=0}^{3} p_k(v + \frac{1}{2})^k$. For $P_v = T_v$, $p_0 = T_e$, $p_1 = \omega_e$, $p_2 = -\omega_e x_e$, $p_3 = \omega_3 y_e$, while for $P_v = B_v$, $p_0 = B_e$, $p_1 = -\alpha_e$, $p_2 = \gamma_e$, etc.

[b] Standard deviation of fit, 1.0992 (unweighted rms deviation, 0.0054 cm^{-1}) involving 6120 data points and 59 adjustable parameters. Numbers in parentheses are uncertainties quoted to 1 standard deviation. Determined molecular constants for $v = 1$ of $B\ ^3\Pi$: $T_1 = 17515.910342(347)$, $B_1 = 0.502865452(249)$, $D_1 = 6.90743(127) \times 10^{-7}$, $H_1 = 1.369(192) \times 10^{-13}$, $A_1 = 20.788458(243)$, $A_{D1} = -1.1435(280) \times 10^{-4}$, $A_{H1} = -6.469(115) \times 10^{-9}$, $\gamma_1 = 0.0249132(569)$, $\lambda_1 = -0.930701(256)$, $\lambda_{D1} = -3.791(719) \times 10^{-6}$, $\lambda_{H1} = -5.27(175) \times 10^{-10}$, $o_1 = -0.618632(284)$, $o_{D1} = 1.952(467) \times 10^{-6}$, $o_{H1} = 3.79(130) \times 10^{-10}$, $p_1 = 0.0261175(102)$, $p_{D1} = 1.1504(359) \times 10^{-7}$, $q_1 = 2.95978(384) \times 10^{-4}$, and $q_{D1} = -6.15(104) \times 10^{-10}$.

TABLE 8

TURNING POINTS FOR THE RKR POTENTIAL ENERGY CURVE OF THE $X\ ^3\Delta$ AND $A\ ^3\Phi$ STATES OF TiO

	$X\ ^3\Delta$			$A\ ^3\Phi$		
v	$E(v)$[a]	r_{min} (Å)	r_{max} (Å)	$E(v)$	r_{min} (Å)	r_{max} (Å)
0.0......	503.3372	1.5699	1.6756	432.8197	1.6102	1.7243
0.5......	1004.5008	1.5502	1.7001	863.6928	1.5892	1.7508
1.0......	1503.3779	1.5356	1.7195	1292.6246	1.5735	1.7718
1.5......	1999.9656	1.5236	1.7363	1719.6316	1.5607	1.7901
2.0......	2494.2601	1.5133	1.7516	2144.6660	1.5497	1.8067
2.5......	2986.2608	1.5041	1.7656	2567.7436	1.5400	1.8220
3.0......	3475.9640	1.4958	1.7788	2988.8683	1.5312	1.8364
3.5......	3963.3658	1.4882	1.7914	3408.0039	1.5231	1.8501
4.0......	4448.4640	1.4812	1.8034	3825.1525	1.5157	1.8632
4.5......	4931.2559	1.4747	1.8150	4240.3053	1.5088	1.8757
5.0......	5411.7385	1.4686	1.8262	4653.4536	1.5023	1.8879

[a] Calculated relative to the minimum of the $X\ ^3\Delta$ potential curve.

TABLE 9

FRANCK-CONDON FACTORS[a] FOR THE $A\ ^3\Phi$–$X\ ^3\Delta$ SYSTEM OF TiO

v'/v''	0	1	2	3	4
0........................	0.7191	0.2365	0.0398	0.0042	0.0003
1........................	0.2362	0.3188	0.3317	0.0971	0.0148
2........................	0.0400	0.3294	0.1038	0.3350	0.0155
3........................	0.0044	0.0976	0.3291	0.0143	0.2860
4........................	0.0003	0.0159	0.0155	0.2758	0.0020

[a] Calculated from the RKR curves of Table 8.

ular constants including the spin-orbit splitting constants and spin-spin constants for $v = 0$. This, in turn, results in the reliable spin constants in the excited $A\,^3\Phi$ state and in the excited vibrational levels of the ground state. Our constants for the $X\,^3\Delta$ $v = 0$ level are in excellent agreement with the constants of Amiot et al. (1995). The present $A\,^3\Phi$ state constants agree only moderately with the most recent constants of Barnes et al. (1996) because they used an R^2 Hamiltonian and they had a much smaller data set. Our constants are also in good agreement with the less precise constants of Phillips (1973).

Since TiO is the main source of visible and near-infrared opacity in M-type stars (Merrill, Deutsch, & Keenan 1962), our work on the strong γ-bands will result in improved stellar opacity functions. Currently the best TiO opacities are those of Jorgensen (1994), but recent experiments (Hedgecock et al. 1995) and calculations (Langhoff 1997) have resulted in substantial changes in the oscillator strengths of many transitions. New TiO opacities have been calculated by Schwenke (1998), who combined both theoretical predictions and experimental data.

4. SUMMARY

In conclusion, we have observed the $A\,^3\Phi$–$X\,^3\Delta$ transition of TiO in the laboratory as well as in sunspot spectra. The Fourier transform measurements of several bands of the $A\,^3\Phi$–$X\,^3\Delta$ transition have been combined with the previous sub-Doppler measurements of the 1–0 band of the $B\,^3\Pi$–$X\,^3\Delta$ transition (Amiot et al. 1995), with laser excitation measurements of low J lines of the $A\,^3\Phi$–$X\,^3\Delta$ transition (Barnes et al. 1996) and a pure rotational transition in the $X\,^3\Delta$ ground state (Steimle et al. 1990; Namiki et al. 1998), to obtain an improved set of molecular constants. Our constants are expected to be more precise than those previously determined and should prove helpful in the modeling of cool stellar atmospheres and in the calculation of molecular opacities.

We thank J. Wagner and C. Plymate of the National Solar Observatory for assistance in obtaining the spectra. We thank C. Amiot for providing the unpublished line positions of the 1–0 band of the $B\,^3\Pi$–$X\,^3\Delta$ transition. We also thank T. C. Steimle for bringing to our attention their recent work on the measurements of pure rotational transitions of the ground state and providing the list of lines before publication. The National Solar Observatory is operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation. The research described here was supported by funding from the NASA laboratory astrophysics program. Some support was also provided by the Natural Sciences and Engineering Research Council of Canada.

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